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Proceedings of the IERS Workshop on site co-location

Matera, Italy, 23 – 24 October 2003

Edited by
Bernd Richter, Wolfgang R. Dick,
and Wolfgang Schwegmann

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Preface

A workshop devoted to “site co-location survey objectives, methods and issues” has been organized by the International Earth rotation and Reference Systems Service (IERS). It took place in Matera, Italy, on October 23–24, 2003.

Presently the quality of the station coordinates results from the various space techniques is in the order of a few millimetres in the horizontal and about 1 cm in the vertical component. Precise local ties are the perfect link to enable a rigorous combination of all space observing techniques by their common parameters in order

- to study the systematics going along with each space technique and,
- to establish a unique, high-precision terrestrial reference frame.

In previous analysis one of the major limiting factors is the characteristic and the availability of accurate local tie information for all the co-located sites around the globe. In 5 sessions attention has been given to:

- Co-location sites and their importance for the ITRF
- Site surveys
- Analysis and SINEX
- Reporting and Archiving
- Planning for 2004

More than 30 participants from Australia, South Africa, USA and Europe discussed various examples, analysis methods and survey strategies. Finally guidelines for co-location site surveys and report templates have been proposed. The potential availability of survey teams as well as the planning for surveys in 2004 have been investigated.

The important recommendations are the following:

- Local ties between co-located instruments should be determined with an accuracy of 1 mm, with full variance/covariance information, available in SINEX format.
- Local survey measurements should have the same importance as and should be treated like any of the space geodetic techniques. Site coordinates (VLBI, GPS, SLR, DORIS) should be better tied to the ground. The local ties quality should be such that they can be assumed true for the combination.
- All GPS sites close to other geodetic techniques should be part of the IGS routine processing.
- A database will be established at IERS (Central Bureau and ITRS Product Centre) for all information in connection with site co-location (list of co-location sites, local ties in SINEX, co-location instruments, site maps and pictures, survey reports, survey status, site events and history ...).

To support the local tie activities an IERS Working Group on Local Survey will be suggested for adoption by the IERS Directing Board. The charter of the working group will be the coordination and assistance in local tie analysis as well as SINEX file generation.

Bernd Richter

ITRF, Combinations and Site Co-locations

Claude Boucher

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This keynote to the Workshop held on Matera was given both as responsible of the ITRF Product Center of IERS and as new president of the IAG SBu-Commission 1.2 on Global Reference Frames. I consider here three major topics, different but closely imbricated.

1 Site equipments and surveys

A site is a topographic location with permanent or temporary instruments, and markers.

A site survey is any connexion between points with conventional or GPS surveys.

Several issues of interest for us should be reminded here, in particular:

- Perennity of the site (partial destructions)
- Stability of various components of the site
- Calibration of instruments (e.g. SLR)
- Footprint, or linking to the crust
- Availability of relevant informations to users (site catalogue)

2 Site co-locations

The current definition is a site with multiple instruments

- Same technique or not
- Simultaneous or not

Site co-location give additional importance of site survey information for the following purposes:

- Comparisons or combinations of solutions
- Mono- or multiple-technique analysis strategy

In the currently accepted organisational scheme of IERS, site survey should be actually considered as a specific technique.

3 Global Geodetic Observatories

The Global Geodetic Observatory (GGO) concept has already been the topic for various investigations, such as

- In former CSTG, ISGN label
- Global Observing Systems, IGGOS...

We must also consider GGO as a High level Site co-location

- Through the multiplicity of techniques
- Realizing interdisciplinarity between geodesy and others (meteorological equipments, time and frequency equipments, tide gauges, sismometers...)
- Focusing on the perennity of datum definition

4 The ITRF point of view

As already expressed many times, ITRF activity focuses on:

- Importance of site co-locations in ITRF determination
 - Multi-technique combination (ties between tracking instruments)
 - Redundancy for quality assesment, statistical tests
 - Datum definition (ITRF Core Co-location Site)
- Importance of local survey, as additional technique , like SLR...
 - SINEX with time variations

5 The IAG SC 1.2 point of view

We propose to establish a joint WG with IERS. For SC1.2 we have identified it as WG2 on Global geodetic observatories. The topics of investigation for such a group could be, without limitation:

- Concept of GGO
- Site surveys
- Site effects
- Co-location strategies

The SC will concentrate on research issues, while IERS on operational aspects.

In conclusion, I want to reassess the leading role of IERS for these issues, and welcome the close joint work between IERS and IAG.

I also express once again the critical impact of local survey informations for ITRF activities (see the following paper by Zuheir Altamimi).

ITRF and Co-location Sites

Zuheir Altamimi

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With contributions of Angelyn Moore, Axel Nothnagel, Van Husson, Hervé Fagard and Markus Rothacher

Abstract. The main focus of this position paper is to review the current status of the co-location sites, necessary for ITRF combination. The definition of a co-location site is given in terms of distance between geodetic markers or instrument reference points of different techniques and accuracy of the local ties connecting them. Distribution and quality of the current co-location site are summarized. Given the precision increase of the measurement of the space geodesy techniques and modelling, 1 mm precision or better should be the goal of all new local tie surveys. Moreover, SINEX files with full variance-covariance information is now mandatory.

1 Introduction

When combining TRF solutions of station coordinates provided by different techniques, it is essential to be able to connect these solutions. This could not be possible without having common observing sites of the various techniques. The common sites (co-locations) have different instruments and observing monuments for which differential coordinates (local ties) should be available for TRF combination purpose.

Co-location sites represent a key element of the ITRF combination, connecting the individual TRF networks together. Without co-locations an inter-technique combined TRF could not exist. A global homogeneous geographical distribution of co-locations is desired and the quality of local ties must be high.

2 Definition of a Co-location Site

A co-location site is defined by the fact that two or more space geodesy instruments are occupying or have occupied simultaneously or subsequently close locations which are very precisely surveyed in three dimensions, using classical or GPS surveys. We designate throughout this paper by “geodetic marker” or simply “marker” an unambiguous, fully defined reference point in space for which we estimate (refer) geodetic coordinates. The marker could be either:

- a well defined physical point anchored/settled in a geodetic monument (pillar, pole, etc.), or
- an instrument reference point (e.g. intersection of axes of SLR telescope or VLBI antenna, GPS/DORIS Antenna Reference Point)

There are at least two main criteria which could be considered for the definition of a co-location site:

- 1 **Inter-marker distance:** typical distance between geodetic markers in a co-location site is of the order of few hundred meters. One could impose a given “maximum” length of distance between markers for an ideal co-location site. Meanwhile the current reality of the available co-location sites (insufficient number and distribution) lead to consider distances up to 30 km (e.g. Tidbinbilla/Orroral complex site). Moreover, footprint network and repeated survey should be established for local site long-

term stability. In any case the accuracy of the local tie should be properly taken into account in TRF combination.

- 2 **Accuracy of the local tie:** the typical uncertainty (when available) of the currently available local ties for ITRF combination ranges between 1 to 3 mm (sometimes larger than 3 mm for imprecise ties)¹. Given the precision increase of the measurement of the space geodesy techniques and modelling, 1 mm precision or better should be the goal of all new local tie surveys. Moreover, SINEX files with full variance-covariance information is now mandatory.

3 History and current status of Local Ties in Co-location Sites

The currently available local ties used in ITRF combinations were collected by the IERS ITRS-Product Center starting in the 1980's. They are from diverse sources and of various qualities, very often without variances.

3.1 Local Ties Usage in ITRF Combination

In ITRF combination, the local ties are used as observations, with proper variances.

The procedure adopted for ITRF2000 combination is to include local ties as independent solutions per site with full variance matrices using SINEX format. Unfortunately, local tie SINEX files were submitted to ITRS PC by only one group: The Australian Surveying and Land Information Group (AUSLIG) for all the Australian co-location sites. Consequently, the other local ties used in the ITRF2000 combination were first converted into a complete set of positions for each site, provided in SINEX format. This has been achieved by solving for the following system of observation equations (1):

$$\begin{pmatrix} \Delta x_s^{i,j} \\ \Delta y_s^{i,j} \\ \Delta z_s^{i,j} \end{pmatrix} = \begin{pmatrix} x^j - x^i \\ y^j - y^i \\ z^j - z^i \end{pmatrix} \quad (1)$$

where $(\Delta x_s^{i,j}), (\Delta y_s^{i,j}), (\Delta z_s^{i,j})$ are the geocentric components of the tie vector linking two i and j , of a given data set s . The standard deviations (SD) $(\sigma \Delta x_s^{i,j}, \sigma \Delta y_s^{i,j}, \sigma \Delta z_s^{i,j})$ for each local tie vector are used to compute a diagonal variance matrix. If these SD are not available, they are computed by :

$$\sigma_{computed} = \sqrt{\sigma_1^2 + \sigma_2^2} \quad (2)$$

where, $\sigma_1 = 3 \text{ mm}$, and $\sigma_2 = 10^{-6} \times \sqrt{(\Delta x_s^{i,j})^2 + (\Delta y_s^{i,j})^2 + (\Delta z_s^{i,j})^2}$.

The equation system (1) needs of course initial coordinates for one point per tie vector set s , which are taken from ITRF solutions. The local tie information should be completely independent of the geocentric site coordinates.

The ITRF Report 4 on local ties (Altamimi, 2001), available at: <http://lareg.ensg.ign.fr/ITRF/ITRF2000/ITRF2000.TIE-prob>, summarizes local tie problems in co-location sites as a result from the ITRF2000 analysis:

¹ Note that within a co-location site, several geodetic markers per techniques are often present. Therefore the accuracy of local ties between pair of markers may vary from one vector to another depending on the quality of the available survey.

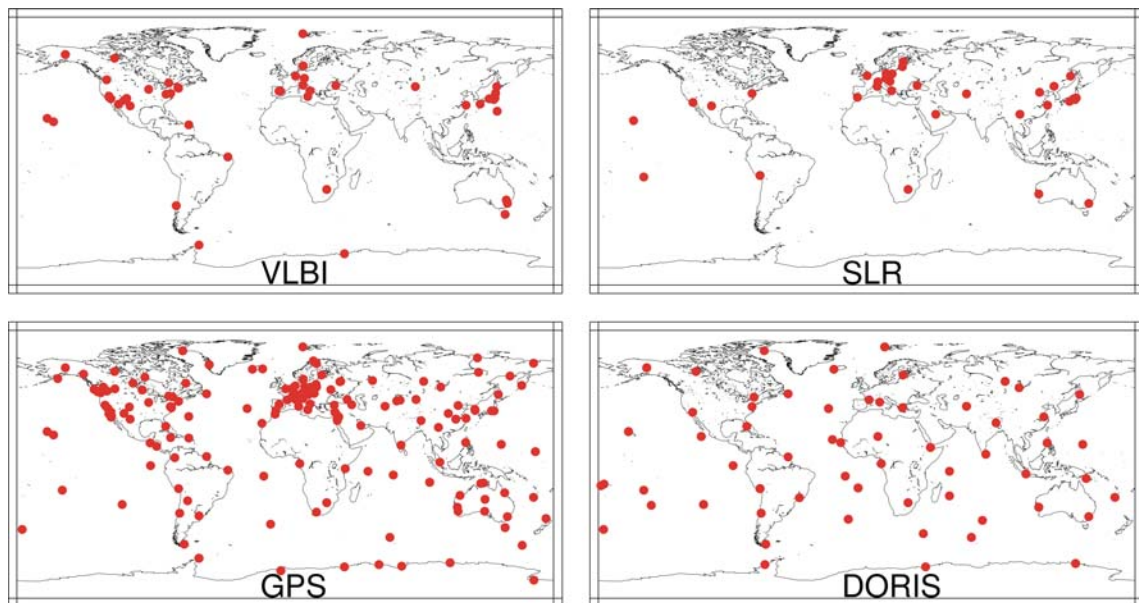
- ITRF2000 contains 101 sites having 2 (72 sites), 3 (25 sites) or 4 (6 sites) collocated techniques
- the number, distribution and quality of the ITRF2000 co-locations were insufficient and old SLR-VLBI mobile co-locations are now obsolete
- 200 local tie vectors were included in the combination
- 38 local tie vectors were missing, 25 of which are highly important
- 20 vectors were declared as dubious: post fit residuals ≥ 1 cm.

3.2 Current Situation

The sites where stations of the 4 major techniques are currently operating (i.e. over the past 5 years) are illustrated in Figure 1. VLBI and SLR networks each include less than 50 sites. DORIS network is more homogeneous and includes 56 sites. Finally IGS GPS network is containing more than 300 permanent sites (actually 362 IGS stations, at the time of writing). Note on the other hand that there are far more than 1000 continuously and permanently observing GPS stations around the world due to regional denser networks whereas the IGS maintains a global focus. This huge number of GPS permanent stations is deployed thanks to, mainly, GPS easy use and low cost, compared to the other techniques. This GPS particularity, coupled with its high precision reached now thanks to IGS in particular, is of great interest to IERS and IAG IGGOS project, since it allows strengthening somehow the current situation of IERS co-location sites. In short, we should have a GPS permanent station at each VLBI and SLR sites (DORIS/GPS co-location sites are already numerous and well distributed), thus leading to reinforce the connection between these three techniques. On the other hand, GPS permanent stations collocated with SLR and/or VLBI should become IGS core stations and be analyzed by IGS ACs regularly.

The quality and distribution of the recently operating collocated stations are presently questionable and deserve more attention for improvement. Figure 2 shows the co-location sites (approximately 72 sites) where at least two of the 4 techniques (VLBI, SLR, GPS and DORIS) have been recently operating (for the past 5 years). While 58 sites are hosting 2 observing techniques, only 12 sites are having 3 techniques (with inhomogeneous distribution over the globe) and, more dramatically, only 2 sites with the 4 techniques. Moreover, as results from the combination analysis developed below, there are 8 sites where the local ties are inconsistent with space geodesy estimates and 8 sites with missing ties. The current status and distribution of co-locations, taken by pair of techniques, are as follows (based on the available information at the ITRS Product Center):

- SLR and VLBI observing stations are poorly distributed;
- VLBI session observing networks are very sparse and not all connectable in terms of common stations, over periods less than a year.
- For the upcoming IERS Combination Pilot Project, the number of VLBI co-locations with other techniques (1) may not be sufficient in a weekly basis and (2) are not the same from one week to another. This may lead to a weak connection of the VLBI network to the other techniques.
- The current number of SLR-VLBI co-location sites does not exceed 6;
- Almost all active VLBI and SLR stations are collocated with GPS, but there are still 6 SLR sites not collocated with GPS
- Only 8 VLBI-DORIS co-locations exist and they are not well distributed
- Only 7 SLR-DORIS co-locations exist and they are not well distributed: 5 in the southern hemisphere and 2 in the northern hemisphere



- There are about 30 well distributed GPS-DORIS co-locations
- The current available local ties are values at different (mostly unknown) epochs and they are thus considered as static, i.e. without time variation. For future improvement of the combination results, it is important to consider time variations of the local ties. This implies organizing repeated (yearly!) surveys at the co-location sites.

With some international cooperation via national surveying agencies, the situation of missing and inconsistent ties could be easily improved. Meanwhile, the long term maintenance of co-location sites and their distribution need more attention. The urgent action is to envisage new design of ITRF Core Co-location Sites (ICCS), the indispensable “ITRF Pillars”, with global coverage, stable and solid monumentation, regularly/repeatedly surveyed and geophysically monitored. For instance, extensive description and specifications to reinforce and secure the IGS Reference Stations were recently formulated by Ray (2003), which could be extended and adapted to the ICCS.

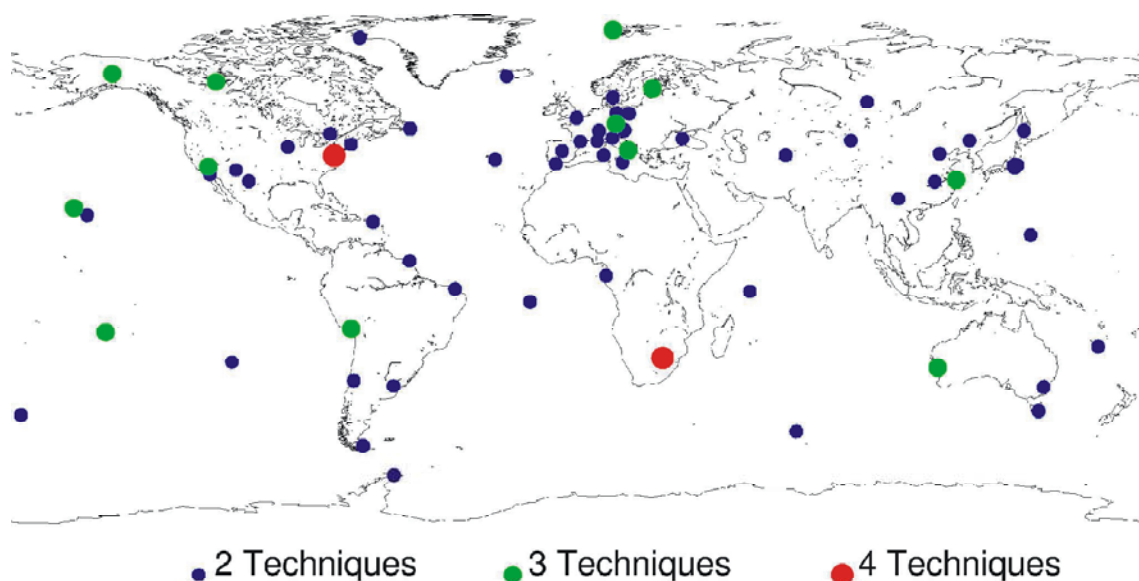


Figure 2: Current co-locations of space geodetic techniques (Since 1999)

3.3 New Local Ties Evaluation

After the ITRF2000 report 4 on local ties, it seems necessary to evaluate the current situation of the available local ties. A global combination test was then performed based on the following time series data:

- VLBI: 24h-session SINEX files over 1990-2003, provided by Goddard Space Flight Center (GSFC) VLBI Group, using the terrestrial reference frame of gsfd001 (IVS, 2003),
- SLR: weekly solutions over 1993-2003, provide by the Italian Space Agency (ASI), (Luceri, 2003),
- GPS: Official IGS weekly combined solutions over 1999-2003 (Ferland, 2003)
- DORIS: IGN-JPL weekly solutions over 1993-2003 (Willis, 2003).

As results of this combination tests, Tables A1 and A2 in the appendix list the missing and inconsistent (dubious) tie vectors. Table A2 lists differences, in geocentric and local frame, larger than one centimeter (2 cm in case of DORIS ties to the other techniques) between the available local tie values and space geodesy estimates as results from the multi-technique test combination. Concerning Table A2 it is possible to identify which point is most dubious when at least 3 systems are present, as for example 12734/Matera VLBI 40424/Kauai GPS.

3.4 Priority list of Problematic Sites

Based on ITRF2000 analysis and the combination test presented here, Table A3 of the appendix lists the priority sites to be (re)-surveyed. The site selection is based on the following criteria:

- Missing ties
- Critically inconsistent (dubious) ties: differences larger than 1 cm for VLBI/SLR/GPS and 2 cm for DORIS sites, see table A2 of the appendix
- Co-location sites after an Earthquake

4 Recommendations

Some important recommendations related to local surveys and co-location sites were already addressed during the IERS Workshop in Munich 2002 (Altamimi et al, 2002). These recommendations are reproduced, emphasized and augmented below.

Recommendation 1: In order to improve co-location sites distribution and observing networks:

- International effort is needed to improve VLBI-SLR co-locations by installing new SLR systems (e.g. SLR2000) at all VLBI sites. These are very critical for the long term TRF scale maintenance.
- IVS is urged to schedule repeated Global-TRF observing sessions;
- IDS is asked to consider installing DORIS beacons at all SLR and VLBI sites, starting with sites collocated with GPS in order to augment the number/distribution of the 4-technique “primary” sites.

Recommendation 2: The Working Group on Local Ties is asked to organize repeated (yearly !) local surveys at all available co-location sites. Per-site local tie components (at the survey epoch) and their time variations should be provided in SINEX format with full variance-covariance matrix. The priority list of sites (re-)surveys should be organized as follows:

- start with sites where local ties are missing and critically dubious, e.g. Shanghai
- after Earthquakes, e.g. Arequipa, Fairbanks
- Sites for which full SINEX files are not available, so that ultimately all co-location sites should have local ties expressed in SINEX format. It might be possible that full SINEX files can be computed for surveys performed in the past (if the necessary information is still available or can be recomputed).

Recommendation 3: The IERS Directing Board is asked to consider establishing Associated Analysis Centers for Local Ties survey and analysis, analogous to the existing Analysis Centers of space geodesy techniques.

Recommendation 4: For the long term maintenance of co-location sites and thus the ITRF global stability, the urgent action is to envisage new design of ITRF Core Co-location Sites (ICCS), the indispensable “ITRF Pillars”, with global coverage, stable and solid monumentation, regularly/repeatedly surveyed and geophysically monitored.

Recommendation 5: The technique services (IGS, IVS, ILRS, IDS) should try to detect and assess the size of systematic biases that may be present in their solutions.

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Appendix

Table A1: Currently Missing Ties: Not available at ITRS PC
(October 2003)

DOMES	Name	Techniques involved
12329	YUZHNO-SAKHALINSK	GPS-DORIS
12337	SIMEIS KATZIVELY	SLR-VLBI
12725	CAGLIARI	GPS (CAGZ)-SLR
14201	WETTZELL	VLBI TIGO-SLR/GPS
21602	WUHAN	SLR-GPS
21605	SHANGHAI	GPS-SLR/VLBI
21609	KUNMING	SLR-GPS
21612	URUMQI	VLBI-SLR/GPS
21729	USUDA	GPS-VLBI
30314	SUTHERLAND	GPS SUTM - SLR
40419	KODIAK	Mobile VLBI-GPS
40424	KAUAI	DORIS-GPS
40445	MAUI	GPS-SLR
40499	RICHMOND	VLBI-SLR/GPS
41609	CACHOEIRA PAULISTA	GPS-DORIS
41705	SANTIAGO	SLR-GPS
41719	CONCEPCION	TIGO points (Imprecise tie (+/- 2cm))

Table A2: Inconsistent local ties as results from a multi-technique test combination
(October 2003): Differences with space geodesy estimates larger than 1 cm for VLBI-GPS-SLR ties and 2 cm in case of DORIS ties to the other techniques.

Tie Vector		dX	dY	dZ	dE	dN	dUP	CODE	CODE	Techniques	Site Name
FROM	TO	-----cm-----									
10317M003	10317S002	0.2	2.7	-1.1	2.6	-0.9	-0.9	NYA1	SPIA	GPS-DORIS	NY-ALESUND
10503S011	10503S014	-0.5	-0.2	-0.9	0.0	0.1	-1.0	METS	7806	GPS-SLR	METSAHOVI
12349M002	12349S001	-1.8	-2.1	-1.5	1.9	0.8	-2.4	KSTU	KRAB	GPS-DORIS	KRASNOYARSK
12334S006	12334M001	4.7	-4.8	-0.9	-6.3	0.9	-2.6	KIT3	KIUB	GPS-DORIS	KITAB
12717S001	12717M003	-0.7	0.4	0.9	0.5	1.1	0.0	7547	NOTO	VLBI-GPS	NOTO
12734M004	12734S005	0.8	-1.0	-0.3	-1.2	-0.6	0.2	7541	7243	SLR-VLBI	MATERA
12734M008	12734S005	0.8	-1.0	-0.3	-1.2	-0.6	0.1	MATE	7243	GPS-VLBI	MATERA
12734S001	12734S005	0.8	-0.9	-0.9	-1.1	-1.0	-0.2	7939	7243	SLR-VLBI	MATERA
13402M004	13402S007	-2.2	1.1	-1.9	0.9	-0.1	-3.0	SFER	7824	GPS-SLR	SAN FERNANDO
13420M001	13420S001	-1.5	0.2	-0.1	0.1	0.9	-1.2	YEBE	7333	GPS-VLBI	YEBES
14106S011	14106M003	2.2	2.1	3.2	1.5	-0.1	4.1	7841	POTS	SLR-GPS	POTSDAM
21601S004	21601M001	0.8	-1.0	-2.7	-0.3	-1.3	-2.7	7249	BJFS	SLR-GPS	BEIJING
21605S001	21605S009	-2.4	1.3	1.9	1.4	0.5	3.0	7837	7227	SLR-VLBI	SHANGHAI
39801S005	39801M001	7.0	3.4	0.5	-3.8	1.0	6.6	SEY1	MAHB	GPS-DORIS	MAHE ISLAND
40127M003	40127M004	-0.1	0.3	-1.0	-0.2	-0.3	-1.0	YELL	7296	GPS-MVLBI	YELLOWKNIFE
40405S005	40405S019	4.0	3.3	-0.4	2.1	2.4	-4.1	GOMA	1515	DORIS-VLBI	GOLDSTONE
40405S019	40405S035	0.9	0.2	2.6	0.7	2.4	1.0	1515	GOLA	VLBI-DORIS	GOLDSTONE
40405S019	40405S037	-3.5	-3.8	0.5	-1.4	-2.5	4.3	1515	GOMB	VLBI-DORIS	GOLDSTONE
40408M001	40408S004	1.9	2.9	-1.3	-1.4	2.3	-2.5	FAIR	FAIA	GPS-DORIS	FAIRBANKS
40424M004	40424S001	3.0	-1.3	3.3	2.3	4.0	-0.9	KOKB	1311	GPS-VLBI	KAUAI
40424M004	40424S007	3.1	-1.2	3.1	2.2	3.8	-1.1	KOKB	7298	GPS-VLBI	KAUAI
40424M004	40424S008	2.6	-1.6	3.2	2.4	3.6	-0.5	KOKB	KOKA	GPS-DORIS	KAUAI
40442M006	40442S017	-0.4	-0.7	1.0	-0.2	0.4	1.2	7080	7613	SLR-VLBI	FORT DAVIS
40442M012	40442S017	-0.4	-0.9	0.4	-0.2	-0.2	1.1	MDO1	7613	GPS-VLBI	FORT DAVIS
40456M001	40456S001	-1.0	0.9	-0.9	-1.2	-0.4	-1.0	PIE1	7234	GPS-VLBI	PIETOWN
40499M002	40499S001	0.2	0.9	-1.1	0.4	-0.6	-1.2	7295	7219	SLR-VLBI	RICHMOND
41507S005	41507M004	-2.5	1.8	1.9	-1.6	-0.9	-3.1	RIPB	RIOG	DORIS-GPS	RIO GRANDE
50103M108	50103S007	2.7	-1.0	1.6	-0.5	-0.3	-3.2	TIDB	7843	GPS-SLR	TIDBINBILLA
50103M108	50103S202	3.1	-1.1	1.6	-0.6	-0.6	-3.5	TIDB	ORRB	GPS-DORIS	TIDBINBILLA

Table A3: Priority list of co-location sites to be (re)-surveyed

DOMES	Name	VLBI	SLR	GPS	DORIS	Missing	Inconsistent
12329	YUZHNO-SAKHALINSK			x	x	x	
12337	SIMEIS KATZIVELY	x	x			x	
12334	KITAB			x	x		x
12349	KRASNOYARSK			x	x		x
12711	NOTO	x	x	x			x
12734	MATERA	x	x	x			x
13402	San Fernando		x	x			x
14106	POTSDAM		x	x			x
21601	BEIJING		x	x			x
21602	WUHAN		x	x		x	
21605	SHANGHAI	x	x	x		x	x
21609	KUNMING		x	x		x	
21612	URUMQI	x	x	x		x	
21729	USUDA	x		x		x	
39801	MAHE ISLAND			x	x		x
40405	GOLDSTONE	x	x	x	x		x
40408	FAIRBANKS	x		x	x		EQ
40424	KAUAI	x		x	x		x
40442	FORT DAVIS	x	x	x			x
40446	PIE TOWN	x		x			x
40445	MAUI	x		x		x	
42202	AREQUIPA		x	x	x		EQ

Status of the International GPS Service in Terms of Co-Location and Local Ties

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1 Introduction

The IGS network today consists of 364 stations (see Figure 1) managed by about 100 different agencies worldwide. The RINEX observations are contributed (generally on a daily or hourly basis) to the IGS Data Centers, which permanently archive the data and make it freely available to all users. The primary customer of the data set is the IGS Analysis Centers (ACs), which acquire the data for generation of precise GPS products such as ephemerides, clocks, earth orientation parameters, and station positions and velocities. The IGS Network Coordinator (NC) at the Central Bureau acts as liaison between the station operators and the Analysis Centers, collecting and providing necessary station configuration metadata and ensuring the dataset meets the requirements of the analysis.

As noted in other presentation at the Matera Co-Location Workshop, GPS differs from the other geodetic services in this abundance of sites, owing mainly to the relative ease of installation and operation. The IGS values inclusiveness and has historically accepted any site meeting the technical requirements. However, in recent years the network has reached quite satisfactory levels of coverage and redundancy in some areas, which tends to lead to fewer independent analyses of neighboring sites. As an initial measure to control the station population, proposed sites are now asked to state which IGS product or project would benefit from the addition of that site. In some areas, sites can be referred to regional densification networks such as the EUREF permanent network in Europe.



Fig 1 The IGS Tracking network

It should be noted that some areas do still suffer from sparse coverage. The IGS is active in some special efforts to encourage use of geodetic GPS, such as the IAG's AFREF project to establish a continental reference frame for Africa.

2 Site Metadata in the IGS

The IGS requires an up-to-date “site log” (also known as “site information form”) for each site. The latest format¹ for site logs was devised through community discussion in late 2001 and all site logs were moved to this format in mid-2002.

The IGS “SINEX template”² is generated daily at the Central Bureau from official site logs and is the official site metadata set which ACs are requested to use. Included for each site in this file are

- IERS DOMES numbers
- Receiver model and serial numbers, and firmware version
- Antenna model and serial numbers
- Radome type
- Antenna Reference Point → L1 and L2 phase center offsets as defined for that antenna model in the igs_01.pcv file
- Marker → Antenna Reference Point eccentricities

for both current and past time periods. The data in these areas of the site log undergo considerably scrutiny by automatic software processes as well as by the NC.

A “Surveyed Local Tie” section was in fact added to the latest version of the site log format, as demonstrated in Figure 2. There was some discussion on whether one geodetic service is the proper place for local tie information to be assembled, but consensus was that there was no harm in providing the spot to being collecting the data, pending formulation of other plans for local ties in the community.

3 Site Guidelines

A major effort to revamp the IGS Site Guidelines was undertaken in 2003. Experience suggested that operators would appreciate a clear delineation of strict requirements vs. additionally desired characteristics. Also, guidelines are separated out for specific subsets of sites, such as Reference Frame sites, which are determined by the IGS Reference Frame Working Group (chaired by R. Ferland of NRCan). Up to now, the selection process has been informal, but the new guidelines bring the possibility to point operators of the Reference Frame stations to the relevant sections and request confirmation of the ability to adhere to them.

¹ <ftp://igscb.jpl.nasa.gov/pub/station/general/blank.log>

² <ftp://igscb.jpl.nasa.gov/pub/station/general/igs.snx>

5.	Surveyed Local Ties	
5.1	Tied Marker Name	: MATE
	Tied Marker Usage	: GPS Tied Marker CDP Number :
	Tied Marker DOMES Number	: 12734M008
	Differential Components from GNSS Marker to the tied monument (ITRS)	
	dx (m)	:
	dy (m)	:
	dz (m)	:
	Accuracy (mm)	:
	Survey method	: (GPS Campaign/Trilateration/Triangulation/etc)
	Date Measured	: 1991-09-01
	Additional Information	: (multiple lines)
		: UP (m)
		: EAST (m)
		: NORTH (m)
		: DIST (m)
		: exact date in Sep 1991 not known
5.2	Tied Marker Name	: SLR (MARKER O)
	Tied Marker Usage	: SLR
	Tied Marker CDP Number	: 7939
	Tied Marker DOMES Number	: 12734S001
	Differential Components from GNSS Marker to the tied monument (ITRS)	
	dx (m)	: 15.172
	dy (m)	: 24.826
	dz (m)	: -24.959
	Accuracy (mm)	: 2
	Survey method	: TRIANGULATION
	Date Measured	: 1996-07-01
	Additional Information	:
5.3	Tied Marker Name	: VLBI
	Tied Marker Usage	: VLBI Tied Marker
	CDP Number	: 7243
	Tied Marker DOMES Number	: 12734S005
	Differential Components from GNSS Marker to the tied monument (ITRS)	
	dx (m)	: -10.946
	dy (m)	: -42.246
	dz (m)	: 38.203
	Accuracy (mm)	: 6
	Survey method	: TRIANGULATION
	Date Measured	: 1991-11-01
	Additional Information :	

Figure 2: Sample of Local Tie information in an IGS site log

Items specific to local ties and reference frame determination in the current version³ include:

2.2.17 (desired for all sites): 3-dimensional local ties between the GPS marker, collocated instrumentation (e.g. DORIS, SLR, VLBI, gravity, tide gauge) and other monuments should be re-surveyed regularly to an accuracy of 1mm and reported in ITRF.

- The marker → antenna reference point (ARP) eccentricities should be reverified during such a survey.
- Repeat the survey after known motion incidents such as earthquakes.

3.1 About Reference Frame Sites: The IGS Reference Frame Working Group (RFGWG) periodically selects a set of globally distributed, stable sites to be used in reference frame determination. Excellent documentation of site history is particularly critical for these stations, and the station position time series must be free of jumps whose cause or magnitude is not well understood. All IGS products rely on the reference frame to be accurate, reliable, and stable.

The RFGWG has the expertise to weigh station locations and characteristics in choosing the Reference Frame station set. Although there is some motivation to keep stations from one realization of the frame to the next, stations may be removed or replaced as the WG sees fit. All the required and desired guidelines from Chapter 2, Guidelines for all IGS sites are equally, and even more so, required and desired for Reference Frame sites. The characteristics from Section 2.3, “Desired physical characteristics” are also all considered in the selection process and highly desirable. The degree of compliance in many cases will have an effect on time series, residuals, and velocity estimates important to frame determination.

3.2 Additional Reference Frame Site Selection Criteria: The RFGWG will also weigh the following criteria in selecting reference frame sites.

- Significant distance from the nearest reference frame station
- For coordinates and velocities useful to Reference Frame determination, sufficient observing history is needed (usually >2 years)
- Operated by an institution with a long-term commitment and geodetic expertise
- Relation to regional/national geodetic network, if one exists
- Likelihood of site being abandoned or overtaken by other uses should be very low
- Consistently high-quality raw data, with good tracking, low multipath, and low quantity of cycle slips
- Priority is given to stations with nearby installations of other space geodetic systems (SLR, VLBI, and DORIS) and which undergo regular surveys

This reflects biennial resurveys for reference frame sites vs. annual as suggested at the Matera Workshop. One option could be to recommend biennial surveys for all sites and require annual surveys for reference frame sites. Care should be taken, however to make requirements and recommendations that are actually reasonable to expect the operators to attain.

The guidelines were approved by the IGS Governing Board with the proviso that a program of continuous review and improvement be also instituted.

³ <http://igscb.jpl.nasa.gov/network/guidelines/guidelines.html> or
<http://igscb.jpl.nasa.gov/network/guidelines/guidelines.pdf>

Suggestions for alignment with the IERS community are therefore welcome at any time as the co-location and local tie plans and documents are developed.

4 Acknowledgments

The successes of the IGS network are realized thanks to the efforts of the agencies which install and operate the stations.

The network coordination aspect of this work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

Co-Location and Local Tie Information at the International Laser Ranging Service (ILRS)

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1 Introduction

The ILRS supports programs in geodesy, geophysics, oceanography, and lunar research by managing a network of over 40 stations (see Figure 1) that routinely track nearly 30 retroreflector-equipped satellites and five retroreflectors on the Moon to support user needs. Data are routinely provided to the ILRS data centers on a daily and hourly basis. ILRS Analysis Centers, university, government, and other users download these data and produce products to support applications in Earth orientation, station positions and velocities, time varying geocenter coordinates, static and time varying components of the Earth's gravity field, precision orbit determination, fundamental physical constants, lunar ephemerides and librations, and lunar orientation.



Figure 1: The ILRS network in 2003.

New stations must adhere to ILRS requirements to be accepted into the network. New stations are accepted into the ILRS network in associate status upon submission of a complete site log and associated configuration files. Associate stations become operational by:

- delivering at least 10 passes of satellite data to the CB that pass format and data integrity validation by the CB;
- delivering at least 50 LAGEOS passes to an ILRS Data Center that satisfy rms, short-term stability, and acceptance criteria over a consecutive three-month period during the previous 12 months;
- passing data evaluation by the Analysis Working Group;

- having a collocated GPS receiver that is part of the IGS network;
- receiving approval from the Governing Board.

In 2003, a joint NASA-IGN team surveyed the stations in Shanghai China and Hartebeesthoek South Africa to verify the ground surveys to laser monuments and to collocated instruments. The analysis of these surveys is still underway.

2 Site Metadata in the ILRS

The format for the ILRS site log was based upon the successful site log used by the IGS, which was then modified to include laser-system specific parameters. Each site log also contains information about the location of the site and any co-located systems. The ILRS site reference point is assigned a unique four-digit station number and a DOMES number. The DOMES numbering system was developed in the early 1980s as a way to assign an unambiguous identifier to instrument reference points and ground markers; more information about the DOMES numbering system can be found at the ITRF website http://itrf.ensg.ign.fr/domes_desc.php. The ILRS site logs are accessible through the ILRS website¹

The major categories contained the ILRS site log are:

1. System Reference Point (SRP) identification
 - DOMES number
 - monument number
2. Site location information
 - city, country
 - approximate position
3. General system information
 - ILRS code
 - monument and site occupation designator
 - eccentricities
4. Telescope information
5. Laser system information
6. Receiver system
 - primary chain
 - secondary chain
7. Tracking capabilities
8. Calibration
9. Time and frequency standards
 - Frequency standard type
 - GPS timing receiver
10. Preprocessing information
11. Aircraft detection
12. Meteorological instrumentation
13. Local ties, eccentricities, and co-location information
 - Collocated permanent geodetic systems (GPS, GLONASS, DORIS, PRARE, VLBI, gravimeter)
 - local ties from the SRP to other monuments or systems on site
 - eccentricities between other monuments on site
14. Local events possibly affecting computed position
15. On-site, point of contact agency information
16. Responsible agency (if different from 15.)
17. More information

¹ <ftp://cddis.gsfc.nasa.gov/pub/reports/slrlog/>

Station operators are asked to issue updates to their site log whenever major changes occur; old logs are archived. Co-location information, in particular, the three dimensional vectors between the reference points of different space geodetic instruments, is included in the ILRS site log (as it is included in the IGS and IVS site logs). Unfortunately, at this time there is no method (other than human perusal of all logs) for coordinating these entries to ensure they are consistent across the services.

SLR eccentricity information, the three-dimensional vector from the SLR measurement point to a reference marker, is of critical importance to SLR analysis. Eccentricities are measured for both mobile occupations and fixed systems.

Mobile ILRS systems usually occupy and are referenced to a physical ground monument/mark and have an associated set of non-zero eccentricities. System eccentricities are defined as the offsets (usually less than 15 meters) from the ground monument/mark to the optical reference point of the system (i.e., the intersection of the telescope axes). A given monument may be occupied by more than one system or may be occupied by the same system multiple times, but never during the same time period. Therefore, for a given monument and time period, there will be a unique set of eccentricities. A monument is assigned both a station number and DOMES number.

Permanent or fixed systems were designed to remain in one place and usually do not occupy a ground monument/mark. In this case, the reference point is the intersection of the horizontal and vertical axes of the telescope. The system eccentricities are by definition zero. In the rare occasion that a permanent system or its intersection of axes is relocated, new occupation information is recorded (i.e., a new station number and DOMES number).

The ILRS sites are responsible for providing system eccentricity in the site log. The ILRS Central Bureau maintains two SINEX files that contain site eccentricities in North, East, Up and X, Y, Z formats. In these files, each eccentricity set has a unique station number and time frame. These files are available at <ftp://cddis.gsfc.nasa.gov/pub/slocc>.

3 Site Guidelines

ILRS site guidelines are also documented on the ILRS website. ILRS stations must adhere to the following requirements:

- Register with the ILRS (new stations)
- Request identifiers (new stations):
 - Site occupation designator (station number, system number, and occupation number) from the ILRS Central Bureau
 - DOMES number (IERS)
- Deliver data on a hourly/daily basis to ILRS data centers:
 - Normal point
 - Full-rate
- Maintain site files and forward updates to the ILRS Central Bureau for posting on the website:
 - Site log
 - Configuration files
 - System eccentricities
- Maintain station qualification following ILRS criteria

4 Conclusions

The ultimate capability of the integrated geodetic networks can only be realized if the local inter-technique ground surveys are accurately performed, reported, and maintained. Every effort should be made by all IAG services to coordinate these efforts.

5 Acknowledgements

We wish to thank the ILRS stations, operations centers, data centers, and analysis centers for their strong participation toward the continued success of the ILRS.

Local Ties at IVS Sites

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Abstract. At various VLBI sites, but not at all of them, other space geodetic observing platforms are co-located with VLBI telescopes. In this paper we summarize the status of co-locations and of availability of local tie measurements at the time when the ITRF2000 was compiled.

1 Overview of Co-locations at VLBI Sites

The basis of this summary are the ITRF2000 data files without inclusion of installations or local tie measurements carried out since then. Co-locations of DORIS beacons at radio telescopes are not considered ideal. The reason is that the active DORIS beacons often generate radio frequency interference which disturbs radio astronomy observations but also saturates VLBI observing channels at S band which is critical for ionospheric calibration. In a few cases DORIS beacons are located at a larger distance from a VLBI telescope. However, this creates the drawback that the accuracy of the local tie measurements is unsatisfactory. Co-locations of VLBI telescopes and DORIS beacons are, therefore, not considered here. Due to the importance of co-locations of VLBI telescopes and GPS receivers the emphasis of this paper is placed on the GPS equipment at radio telescopes.

32 VLBI sites are listed in ITRF2000 as being co-located with SLR telescopes. However, quite a number of them are older mobile occupations which cannot be considered as usable in the future. 29 fixed VLBI sites are co-located with permanent GPS equipment while 65 VLBI sites, listed in ITRF2000, are not equipped with any other space geodetic technique. However, 42 of these VLBI sites are mobile sites which were only occupied with transportable VLBI telescopes in the early 1980s.

It would be ideal if at least a permanent GPS receiver would be operated at each IVS VLBI site. A great number of the remaining 23 locations without permanent GPS installations are fixed VLBI sites of the Japanese national network (Table 1). It should not be that difficult to establish co-locations within the Japanese GeoNet. The other eleven are distributed all over the world and co-location are partially realized already. If not, the responsible agencies should be made aware of the importance of co-located GPS equipment.

Table 1: List of permanent VLBI sites without co-location of any other space geodetic technique.

Station	DOMES No.	Station	DOMES No.
KASHIMA	21701S001	GOLDSTONE	40405S014
MIZUSAWA	21702S009	GREENBANK	40441S007
KOGANEI	21704S004	LOS ALAMOS, NM	40463S001
MIYAZAKI	21718S001	KITT PEAK	40466S001
NOBEYAMA	21725S001	HANCOCK	40471S001
SHINTOTSUKAWA	21731S001	BREWSTER	40473S001
CHICHIJIMA	21732S001	PARKES	50108S001
MINAMI TORI SIMA	21733S002	SIMEIS	12337S008
SAGARA	21737S001	YEBES	13420S001
MIURA	21739S001	EFFELSBERG	14209S001
TATEYAMA	21740S001	URUMQI	21612S001
AIRA	21742S002		

2 Detailed Information

Although radio telescopes may generate multipath effects or mask a considerable part of the sky for the GPS antenna, both antennas should be located as close together as possible. The reason is that the quality of any local tie measurement and its results strongly depend on the distance between the different observing platforms. Less than 150 m should be considered as optimal while more than 300 m should be avoided. Table 2 gives an overview over the distribution of current separations of the GPS antennas from the radio telescopes at the 29 VLBI/GPS co-location sites.

Table 2: Distances of VLBI and GPS antennas at co-location sites

Distance [m]	# of ties
0 – 50	4
50 – 100	13
100 – 200	7
200 – 500	5

Table 3: Detailed list of the GPS receiver IDs at VLBI telescopes

DOMES No.	Site name		GPS Identifier	Distance [m]	Local Tie available	Formal error available
10317M003	NY-ALESUND	GPS	NYA1	106.343	Yes	Yes
10402M004	ONSALA	GPS	ONSA	22.008	Yes	No
12711M003	MEDICINA	GPS	MEDI	62.765	Yes	Yes
12717M003	NOTO	GPS	NOTO	70.207	Yes	No
12734M008	MATERA	GPS	MATE	58.004	Yes	No
13407S012	MADRID-ROBLEDO	GPS	MADR	265.513	not used	
14201M010	WETTZELL	GPS	WTZR	139.438	Yes	No
21605M002	SHANGHAI	GPS	SHAO	92.044	No	No
21729S007	USUDA	GPS	USUD	104.749	No	No
21730S005	TSUKUBA	GPS	TSKB	303.037	No	No
23903M001	SUWON-SHI	GPS	SUWN	10.221	No	No
30302M004	HARTEBEESTHOEK	GPS	HRAO	163.785	Yes	No
40104M002	ALGONQUIN	GPS	ALGO	112.908	Yes	No
40105M002	PENTICTON	GPS	DRAO	370.040	Yes	No
40405S031	GOLDSTONE	GPS	GOLD	411.520	??	??
40408M001	FAIRBANKS	GPS	FAIR	94.343	Yes	Yes
40424M004	KAUAI	GPS	KOKB	46.480	Yes	Yes
40440S020	WESTFORD	GPS	WES2	57.703	Yes	Yes
40451M123	WASHINGTON	GPS	GODE	33.231	Yes	No
40456M001	PIETOWN	GPS	PIE1	61.800	Yes	No
40465M001	NORTH LIBERTY	GPS	NLIB	67.303	Yes	No
40477M001	MAUNA KEA	GPS	MKEA	87.769	Yes	Yes
40499M005	RICHMOND	GPS	RCM4	142.300	Yes	No
41602M001	FORTALEZA	GPS	FORT	53.344	Yes	No
43201M001	SAINTE CROIX	GPS	CRO1	82.630	Yes	No
50103M108	CANBERRA	GPS	TIDB	375.774	No	No
50116M003	HOBART	GPS	HOB1	60.952	No	No
66006S002	SYOWA	GPS	SYOG	123.787	Yes	Yes
66008M001	O'HIGGINS	GPS	OHIG	51.730	Yes	No

Table 3 contains a detailed list of the GPS receiver IDs at VLBI telescopes together with the distances between the two observing platforms. Often, formal errors are not available from the documentation. This is a severe deficiency of quite a number of existing local ties. No information is available on the quality of the vectors between the observing platforms and it is difficult to decide whether the respective co-location serves its purpose as a proper link between the different reference frames.

Co-locations and Monumentation in the DORIS Network

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COLOCATIONS AND MONUMENTATION IN THE DORIS NETWORK

Hervé FAGARD (Institut Géographique National - France)

Antenna types in the DORIS permanent network

Alcatel

- 10 stations
- Deployed 1986 → 1992
- Point identification: xxxxA

Starec

- 46 stations (+ 2 IDS experiments)
- Deployed as of 1992
- Point identification: xxxB

Survey of a DORIS/Alcatel antenna

Survey of a DORIS/Starec antenna

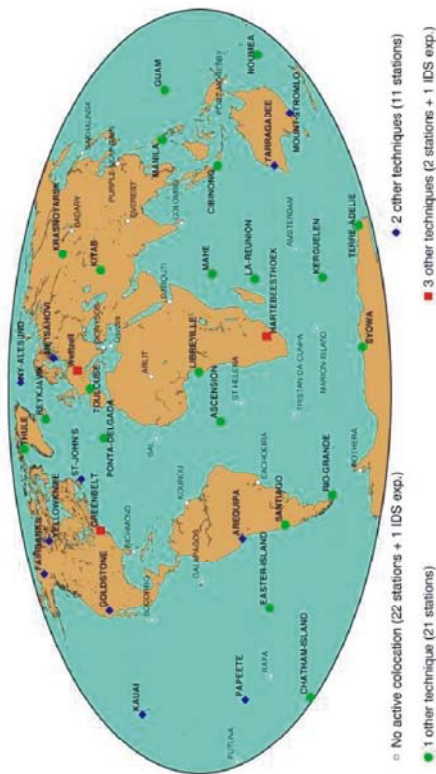
Colocations with other IERS techniques: how active and reliable are they?

- Many instruments colocated with DORIS are not currently operating:
 - Discontinued long-term occupation by:
 - » VLBI (e.g. Richmond, Santiago)
 - » SLR (e.g. Dionysos, Easter Island, Goldstone, etc.)
 - Short duration (2 days only once, to a few days per year) mobile VLBI occupations (Toulouse, Ponta Delgada, Metsähovi)
 - Unreliable tie:
 - Insufficient accuracy, measured only once, sometimes many years ago
 - Very long baseline, different geological movements (e.g. Kourou)
 - Ties to be measured: Sakhalinsk, Cachoeira
- Not all DORIS presumed colocations have the same usefulness for the current realisation of the ITRS

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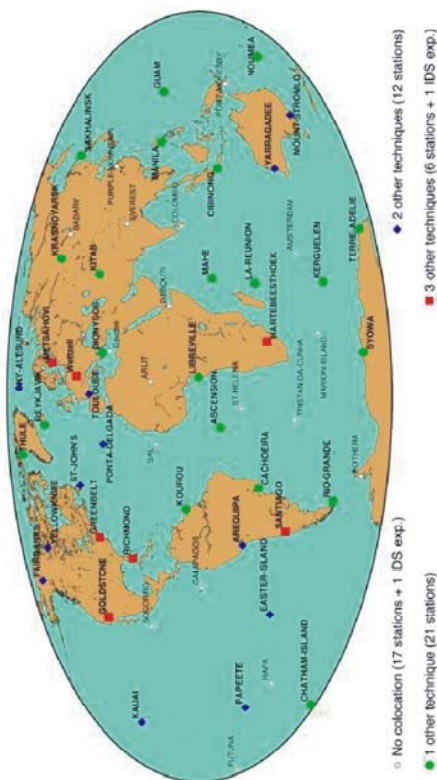
DORIS colocations with active other techniques



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DORIS stations in proximity to other IERS techniques



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Number of colocations: theoretical vs active

DORIS +...	Theoretical	Active & surveyed
GPS	38	34
SLR	12 + 1 IDS exp.	7 + 1 IDS exp.
VLBI	13 + 1 IDS exp.	8 + 1 IDS exp.

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DORIS « internal » colocations (1)

- **31 DORIS stations, out of the 56 making up the current permanent network, have multiple antenna positions (following antenna change or relocation):**
 - Two different antenna positions at 20 sites
 - Three different antenna positions at 10 sites
- **All ties between different antenna positions on the same site have been measured accurately, except:**
 - AMSA-AMSB (approximate connection planned, AMSA no longer exists)
 - HBKA-HBLA (antenna moved by host agency, no direct survey)
 - HELA-HELB (antenna change by host agency, no survey)
 - KERA-KERB (dubious KERA antenna height)
 - GOLA-GOMA (no direct connection)

DORIS antennas stability: general points

The overall antenna stability depends on the stability of:

- The mounting structure:
 - Metal tower (guied or not)
 - Steel pole
 - Metal interface
- The monument on which this structure is installed:
 - Concrete pillar or block (founded or not on the underlying bedrock)
 - Building
- The geological structure on which the monument is located

DORIS « internal » collocations (2)



- 2 DORIS antenna positions

Antenna support: 1st generation (—>1992)



- **Stability requirement: a few cm (expected DORIS positioning accuracy = 10 cm)**
- **Guyed metal tower: guy-wires not always placed so as to guarantee a long term antenna stability**
- **Alcatel antennas:**
 - Phase center position known to within ± 5 mm
 - Difficult to survey and center
 - No accurate verticality adjustment
 - Catches the wind
- **Measured eccentricities after more than 10 years: 1 to 5 cm**

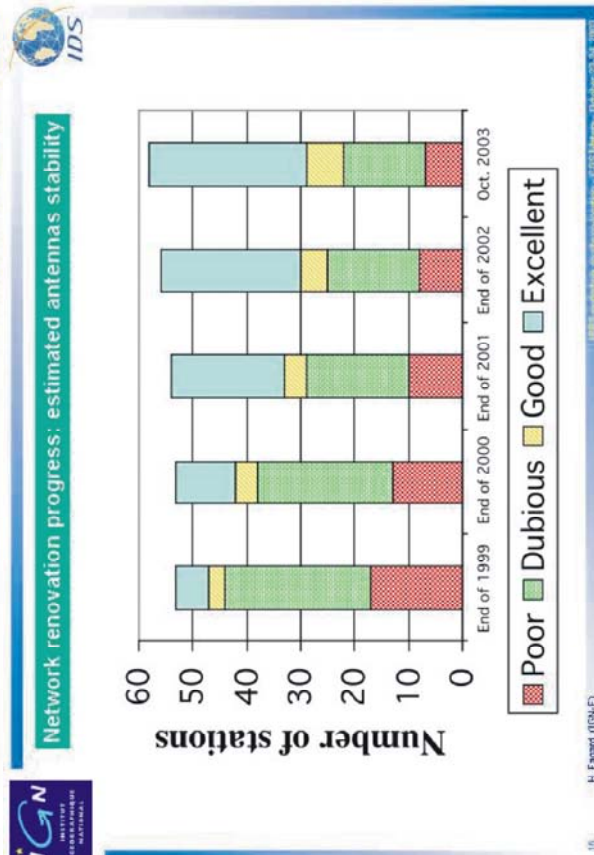
Antenna support: 3rd generation (as of 2000)



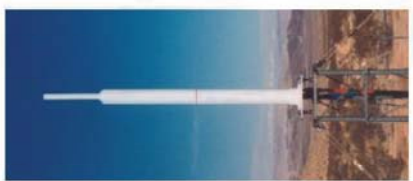
- **Stability requirement: a few mm over 10 years**
(DORIS positioning accuracy approaching 1 cm)
- **Antenna supports:**
 - Forced centering plate on a concrete monument
 - Metal mounting structures not requiring guy-wires
- **Monuments:**
 - Prefer ground installation rather than buildings
 - Concrete structure deeply anchored into the ground (design depends on ground nature)
 - Buildings: low elevation, antenna on a load-bearing wall



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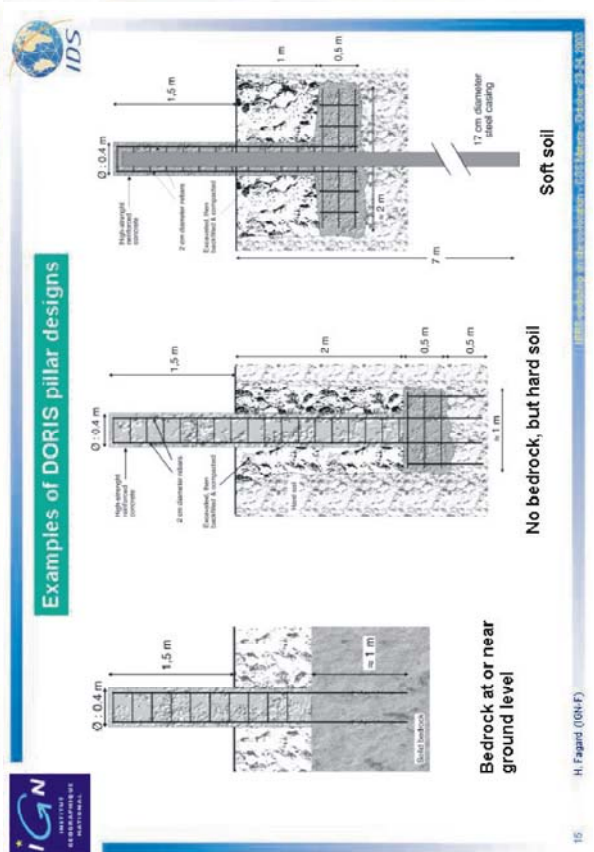


Antenna support: 2nd generation (1993 → 1999)



- **Stability requirement: 1 cm over 10 years**
(Achieved DORIS positioning accuracy = 2 to 3 cm)
- **Starec antennas available:**
 - Phase center position known to within ± 1 mm
 - Easy to accurately survey and center
 - Resist high winds
- **Improved guying and verticality adjustment:**
 - 3 guy-wires at 120° , whose tension is adjusted to reach a mm level centering
 - The supporting plate can be leveled so as to adjust the antenna verticality to within ± 1 mm
- **Excellent short term rigidity and stability, but long term stability still dependent on the guy-wires**

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Analysis of Local Ties from Multi-year Solutions of Different Techniques

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Abstract. Local ties are a key element for the combination of different space techniques. This paper focuses on the analysis of local ties by using multi-years VLBI, SLR, GPS and DORIS solutions. Input are combined intra-technique solutions for each of these space techniques. Major issues are to compare the space geodetic estimated station coordinate differences between co-located instruments with the local ties, and to analyse velocity estimations of different techniques at co-location sites. Based on the obtained results suitable local ties are selected and various aspects regarding the inter-technique combination are discussed.

1 Introduction

The International Terrestrial Reference Frame (ITRF) is computed by combining the solutions of different space geodetic techniques. Currently, the four major techniques are VLBI, SLR, GPS and DORIS, which contribute in different ways to the ITRF realisation. A key element for combining and integrating the reference frame results of the different techniques are co-location sites and local ties to connect the reference points of different instruments. Spatially well-distributed co-location sites and accurate local ties are a prerequisite to fully exploit the unique capabilities and individual strengths of the different space geodetic techniques, and to identify still remaining technique-specific systematic effects (biases).

In its function as ITRS Combination Centre and IERS Combination Research Centre, DGFI is involved in the combination of space geodetic observations. Recently DGFI has done a TRF computation based on the latest multi-years VLBI, SLR, GPS and DORIS solutions containing station positions and velocities (Angermann et al., 2004; Angermann et al., 2005). One critical issue is the handling of local ties within the inter-technique combination. Problems are the sparse global distribution of co-location sites and the fact, that there are only very few co-locations between some techniques (e.g. SLR and VLBI). As known also from ITRF2000 computation and other sources, there are a number of “poorly observed” local ties, a few of them are even dubious (see Altamimi et al., 2002; Altamimi, 2005). Another problem is to achieve a reasonable weighting of local tie information within the inter-technique combination, since in many cases no variance co-variance information of the terrestrial measurements is available. Furthermore it has to be considered that the sparse global coverage and possible errors in local ties may degrade the high internal accuracy of the individual space techniques in the combined solution; thus a proper handling of local ties is a key issue.

Main purpose of this paper is to investigate the impact of local tie information within the combination of different space geodetic solutions and to develop strategies regarding local tie implementation. We applied an iterative combination procedure to identify suitable local ties by comparing the space geodetic estimated coordinate differences between co-located instruments with the local surveys. Within this procedure also the station velocities of different techniques at co-location sites are compared, to identify stable co-location sites and to decide whether the velocities can be forced to be identical. On the other hand the results also contribute to validate the local tie measurements, but it has to be considered that uncertainties and possible sys-

tematic effects (biases) of the space geodetic solutions and datum definition inconsistencies are difficult to separate from local tie errors.

2 Data analysis

The investigations are based on multi-years solutions with station positions and velocities for VLBI, SLR, GPS and DORIS. These so-called intra-technique solutions were obtained from a combination of individual solutions of the same technique (see TRF computation at DGFI, Angermann et al., 2004). The contributing solutions provided by various analysis centres are summarised in Table 1.

Table 1: Summary of solutions used for TRF computation. Stations with an observation time span shorter than one year were excluded.

	AC / solution	Data time span	#stations orig./used	Source
DORIS	GRGS00D01	1993-1998	70/69	ITRF2000
	IGN02D04	1993-2002	111/109	IGN/CDDIS
GPS	IGS03P01	1996-2002	216/207	NRCan
SLR	CRL00L02	1990-2000	62/62	ITRF2000
	CSR00L04	1976-2000	141/106	ITRF2000
	DGFI01L01	1981-2001	113/96	DGFI
	JCET00L05	1993-2000	63/55	ITRF2000
VLBI	DGFI02R02	1984-2002	49/49	DGFI
	GIUB00R01	1984-1999	53/53	ITRF2000
	GSFC00R01	1979-1999	138/88	ITRF2000
	SHA00R01	1979-1999	129/88	ITRF2000

For the selection of suitable local ties we applied an iterative procedure, which is in principle based on two steps:

- In the first step we used the combined intra-technique solutions for each technique to compare the space geodetic estimated coordinate differences between co-located instruments with the official local ties obtained from the ITRF data base¹. In addition, we compared the velocity estimations of different techniques at co-location sites. Each of these intra-technique solutions was solved separately (without any local tie information) by applying no-net-rotation and no-net-translation conditions w.r.t. ITRF2000. Based on these comparisons we identified high quality co-location sites for the inter-technique combination.
- In the second step the normal equations of the techniques are combined using the high quality local ties selected previously. The respective station velocities are set to be equal. This information was introduced by applying pseudo-observations with appropriate weights. The datum of the combined solution is defined in the following way: the origin and its rates are realised by SLR, the scale and its rate by an average of SLR and VLBI. The rotations and their rates are realised using no-net-rotation conditions w.r.t. ITRF2000. Again, the local ties are compared with the space geodetic estimated coordinate differences, and the velocity estimations of co-located instruments are investigated as well. Co-location sites were selected as candidates for the combination, if the observed discrepancies concerning local ties and velocities do not exceed certain criteria (see next chapter). The second step was then iterated, until no further local ties could be identified.

¹ see <ftp://lareg.ensg.ign.fr/pub/itrf/itrf2000/tiesnx/>

3 Realisation of the strategy and results

The selection of local tie information for the combination was performed as described above by comparing the local ties with the station coordinate differences (inter-station vectors) obtained from the intra-technique solutions, as well as the absolute velocity differences between techniques at co-location sites. The results of these comparisons are summarised in Table 2. For six co-locations there is a good agreement between local ties and space geodetic derived inter-station vectors (the absolute differences are below 5 mm), whereas there are many other co-locations (especially those with DORIS), where the discrepancies exceed 3 cm. Regarding station velocity estimations there are eight co-locations with absolute velocity differences below 1 mm/yr, but in many other cases the differences exceed 5 mm/yr. The interpretation of these discrepancies seems to be difficult since many factors have to be considered. So uncertainties of the space geodetic techniques and systematic differences between them, local site effects, such as a different motions of the co-located instruments, small datum inconsistencies between the techniques and errors in the local ties could be the origin for these discrepancies.

Table 2: Comparison of space techniques at co-location sites. Shown are differences between local ties and space geodetic derived inter-station vectors (upper part), as well as absolute velocity differences of co-located instruments (lower part). Note that no redundant local tie information is displayed.

		<i>GPS- VLBI</i>	<i>GPS- SLR</i>	<i>SLR- VLBI</i>	<i>GPS- DORIS</i>	<i>SLR- DORIS</i>	<i>VLBI- DORIS</i>
# co-locations		35	24	12	21	3	1
# local surveys		30	20	10	19	3	1
Δ local ties	< 5mm	3	3	-	-	-	-
	<10 mm	6	5	2	-	-	-
	10-20 mm	10	6	3	3	-	-
	> 20 mm	11	6	5	17	3	1
Δ velocities	< 1mm/a	5	2	1	-	-	-
	1-2.5 mm/a	12	9	5	3	-	-
	2.5-5 mm/a	9	8	3	9	-	-
	> 5 mm/a	8	5	3	9	3	1

As a result of the first processing step we identified six high quality co-locations, three between GPS and VLBI and another three between GPS and SLR. The results for these six stations are documented in table 3. The discrepancies between the space geodetic estimated inter-station vectors and the local ties are below 5 mm (absolute coordinate differences), and the respective station velocities agree within 2.5 mm/yr between the co-located instruments. Furthermore the differences between ITRF2000 station coordinates and local ties are displayed.

In the second step the intra-technique solutions are combined using the six selected high quality local ties. The corresponding station velocities are set to be equal. The information is introduced as pseudo observations with a-priori standard deviations of 1.0 mm and 1.0 mm/yr for local ties and velocities respectively. The datum of the combined solution is defined as described above. Again, the space geodetic estimated inter-station vectors and the local ties, as well as the velocities of the co-located instruments are compared. Now 13 additional local ties between GPS, SLR and VLBI could be selected

by applying less strong criteria than in the first step, i.e. the absolute differences for the local ties should not exceed a boundary value of 10 mm, and the velocities should agree within 4.5 mm/yr (absolute velocity differences). The inter-technique combination is re-iterated by introducing additionally the 13 newly selected ties with a-priori sigmas of 3 mm and 3 mm/yr. This leads to the identification of 18 further suitable co-locations. Performing one more iteration no additional ties meet the criteria stated above. Thus altogether 37 local ties were selected for the inter-technique combination.

So far, only co-locations between GPS, VLBI and SLR were identified, as the discrepancies for co-locations with DORIS exceed the above specified boundary values. Thus a third processing step was necessary to select co-locations between DORIS and the other techniques by applying less strong criteria, i.e. 34.0 mm in the case of local ties and 4.5mm/yr in the case of velocities. As a result 5 local ties could be identified between DORIS and GPS. Another 7 local ties meet the criteria, but these are only ties between different DORIS markers, which are not of importance for the combination of different techniques. Using the 5 local ties between GPS and DORIS, a combination of all four techniques was computed. Similar to the previous combinations the local ties are introduced as pseudo observations with appropriate weights. The a-priori standard deviations for the five additional DORIS-GPS co-locations are 5 mm and 5 mm/yr for local ties and velocities respectively. Again, we performed the same comparisons as before, and identified one additional local tie that could be used for the inter-technique combination. Finally, altogether 50 local ties were selected and introduced in the TRF combination. Table 4 summarises the criteria used in the several processing steps.

Table 3: Differences between space geodetic estimated inter-station vectors and local ties as well as velocity differences at the selected high quality co-location sites. In addition the discrepancies between ITRF2000 station coordinates and local ties are displayed for these sites. Note that the ITRF2000 station velocities were forced to be identical at co-location sites.

Co-location sites	Techniques	Differences in coordinates [mm]			Differences in velocities [mm/yr]		
		$\Delta\varphi$	$\Delta\lambda$	Δh	$\Delta\varphi$	$\Delta\lambda$	Δh
Wettzell,	GPS-VLBI	-0.01	-0.76	3.71	0.17	0.03	0.77
Germany	ITRF2000	-0.07	-0.32	-0.48			
Mauna Kea,	GPS-VLBI	-1.46	-4.75	1.32	-0.07	-0.74	1.89
Hawaii (USA)	ITRF2000	-1.21	-2.46	-2.23			
North Liberty,	GPS-VLBI	-1.68	-2.89	-2.01	-0.79	-0.53	2.23
USA	ITRF2000	-1.04	-1.77	-4.23			
Potsdam,	GPS-SLR	2.85	1.75	-2.81	0.15	-0.03	0.29
Germany	ITRF2000	0.81	0.92	-0.97			
Graz,	GPS-SLR	3.61	-0.19	1.84	-0.02	-0.37	0.85
Austria	ITRF2000	1.29	-0.32	0.79			
Yarragadee,	GPS-SLR	-1.18	0.61	-3.14	0.84	-0.92	0.46
Australia	ITRF2000	-0.43	0.29	-0.31			

Table 4: Summary of criteria applied in the combination procedure for the selection and implementation of local ties.

	# selected ties	criteria	a-priori sigmas
Step I	6	Local ties [mm]	5,0
		Velocities [mm/yr]	1,0
Sep II	31	Local ties [mm]	10,0
		Velocities [mm/yr]	4,5
Step III	13	Local ties [mm]	34,0
		Velocities [mm/yr]	4,5

4 Aspects related to the datum definition

The procedure applied in this paper to select suitable local ties requires a consistent datum definition for the different space techniques. As described earlier, in the first processing step the intra-technique solutions were solved separately by applying no-net-rotation and no-net-translation conditions w.r.t. ITRF2000. This datum realisation depends on the accuracy of ITRF2000 station coordinates and velocities, and on the station distribution of the different space geodetic networks. Thus the space geodetic estimated inter-station vectors and the station velocities of co-located instruments might be influenced to a certain extent by possible inconsistencies related to the datum definition, which consequently would also affect the results presented in the previous chapter.

To investigate the stability of the datum definition and the consistency of the selected local ties with the space geodetic solutions we applied the following approach. Since GPS is the dominant technique regarding the number and spatial distribution of co-locations with the other techniques we consider the GPS solution as reference for this specific investigation. We used the co-location sites and local ties selected in the previous chapter to refer the SLR and VLBI solutions to the GPS reference frame. This was done by adding the local tie components to the SLR and VLBI station coordinates. Thus the “transformed” SLR and VLBI station coordinates refer to the GPS reference point at the selected co-location sites. Then we performed an unweighted 7 parameter Helmert transformation between the GPS solution and the “transformed” VLBI and SLR solutions. In a first iteration we used all co-locations (16 GPS-VLBI, 15 GPS-SLR), whereas in a second transformation the stations with the largest residuals are excluded. The results are summarised in table 6. In both cases the transformation parameters are well below 5 mm. The values itself should not be overinterpreted due to a comparatively poor distribution of co-location sites. The discrepancies between both Helmert transformation versions are in the order of 2-3 mm, which is in the same order as the standard deviations of the transformation parameters. Furthermore the results show, that the standard deviations do not significantly improve if the stations with the largest residuals are excluded from the transformation. Note that the values for the standard deviations might be a little too pessimistic, since the contribution of all co-locations to the estimation of the transformation parameters was the same. Whereas in the combination the local ties were introduced in hierarchical groups with appropriate weights, and so the effect of poorer local ties is smaller. Based on these results we estimate that the level of 2-3 mm might be reasonable for the today's accuracy for the datum definition of the combined solution.

Table 5: Transformation parameters and their standard deviations derived from a 7 parameter Helmert-transformation of the SLR and VLBI network w.r.t. the GPS network using co-location stations as transformation stations.

		<i>VLBI</i>		<i>SLR</i>	
# Transformation stations		16	12	15	10
Translation	X [mm]	0.6 ± 2.4	1.2 ± 2.0	-2.3 ± 1.9	2.5 ± 1.6
	Y [mm]	3.1 ± 2.4	1.2 ± 2.0	2.1 ± 1.9	-1.6 ± 1.6
	Z [mm]	-1.2 ± 2.4	2.5 ± 2.0	2.6 ± 1.9	-2.1 ± 1.6
Rotation	X [mm]	4.8 ± 2.9	4.7 ± 2.6	4.6 ± 2.4	3.7 ± 1.9
	Y [mm]	-3.0 ± 2.6	-4.7 ± 2.2	1.3 ± 2.2	0.2 ± 1.9
	Z [mm]	-1.5 ± 2.7	-2.9 ± 2.2	0.2 ± 2.3	4.0 ± 1.9
Scale	[mm]	2.8 ± 2.3	1.2 ± 1.9	-2.6 ± 1.8	3.3 ± 1.5

5 Conclusions

Co-location sites and local ties are a key element for the combination of solutions from different techniques. The results of this paper clearly show that both, the current situation regarding the distribution of co-location sites and the quality of local ties is not satisfying. Only a few excellent local ties were identified by comparing the space geodetic results with the terrestrial data. For a large number of co-locations and local ties the observed discrepancies are not tolerable for a precise reference frame. An interpretation of the remaining discrepancies between local ties and space geodetic estimated inter-station vectors is difficult, since various factors have to be considered, such as systematic biases between space geodetic solutions, local site effects, errors in the terrestrial measurements, remaining inconsistencies related to the datum definition. Regarding a better separation of these effects and to identify technique- and solution-specific biases, the local ties should be available with the highest possible accuracy.

Furthermore most of the co-locations are primarily between GPS and the other techniques. There are for example only a small number of “direct” local ties between SLR and VLBI stations. Thus the combination of the different techniques is an “indirect” approach mainly via the GPS station network, which is rather problematic for the identification of technique-specific biases. Taking into account the today’s situation regarding co-location sites and local tie accuracy, the selection of suitable local ties is an important aspect, to ensure that poorly observed local ties do not degrade the high internal accuracy of the space techniques within the combination.

In future, it is essential to achieve improvements regarding the distribution of co-location sites and the accuracy of local ties. Furthermore the full variance-covariance information should be available for all local ties (preferable in SINEX format) to allow a “correct” handling of the local ties within the inter-technique combination. These are important requirements to fully exploit the unique capabilities and the individual strengths of the different space techniques within an Global Geodetic Observing System (GGOS).

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Surveying the GPS-VLBI Eccentricity at Medicina: Methodological Aspects and Practicalities

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Summary: This paper describes our experiences in measuring the GPS-VLBI eccentricity at Medicina (Italy). It has been re-measured yearly during three different terrestrial surveys (2001, 2002 and 2003) and corresponding SINEX files with full variance covariance information were produced. The eccentricity vector connecting the GPS and the VLBI reference points has been measured within slightly different local ground control networks and high accuracy has been sought since the first campaign. The methodology has been refined year after year. We describe the choices that concern stationing, selection of instruments, devices and surveying strategies.

1 Introduction

Local ties link together single technique solutions and play an important role in order to reach the highest accuracy in combined multi-technique geodetic products.

In order to measure the relative positions of reference points of co-located techniques, we have developed a surveying strategy that is closely linked to the geometrical model that we have adopted. Moreover, a rigorous statistical approach for the estimation of the eccentricity vector along with a complete variance covariance information must be applied.

It is essential to maintain and regularly survey local networks in order to monitor the stability of the eccentricity and of the co-location site itself. The time spanning between successive surveys is related to the observed stability of the site: Medicina, due to the presence of land subsidence, requires yearly repeated measurements.

Taking into account the short distances that characterize the extension of the local ground control network, which are below a few hundreds meters, local ties can be performed using only terrestrial observations. In order to make the tie effective for an accurate use in ITRF combination, (Altamimi et al., 2002), an accuracy of 1 mm level should be the target.

We identify few successive steps in performing a local tie:

- site surveying and related issues (instruments, devices, surveying strategy, etc...)
- data reduction and least squares estimation of observed targets coordinates
- 3-D least squares geometrical modelling of previously estimated coordinates
- SINEX generation.

A detailed description of the methodology can be found in Sarti et al., 2004. We are presenting here the surveying approach we have developed at Medi-

cina Observatory during 2000, 2001, 2002 and 2003 campaigns (Sarti et al., 2000, Vittuari et al., 2001) along with some selected results.

The eccentricity vector at Medicina was previously observed by other groups applying different methodologies (Cenci et al., 1998; Del Rosso and Ambriaco, 1995; Nothnagel and Binnenbruck, 2000).

2 Local terrestrial survey for GPS-VLBI eccentricity determination

We determine the coordinates of the targets that identify the local ground control network in which the eccentricity is framed and measured.

The choice on the number and quality of instruments and devices is crucial in order to ensure the highest precision.

Our surveying approach is strictly related to the geometrical definition and realization of non-materialised antenna reference points. We make wide use of symmetry considerations in surveying both VLBI and GPS antenna reference points.

2.1 Control network

The Medicina control network is formed by three concrete pillars with Wild-type forced centring markers. These pillars are far from establishing a well-designed local ground control network and this causes a critical lack of standpoints when surveying the eccentricity. The inhomogeneous distribution of observations on the East side of the VLBI antenna can be avoided using temporarily installed tripods. All targets are surveyed searching for the largest redundancy, using forward intersection, measuring azimuth and zenith angles and distances.

In ITRF computation, the tracking points of each technique are uniquely identified using a DOMES (Directory Of MERit Sites) number assigned by the International Earth rotation and Reference systems Service (IERS). In order to establish a local reference frame and supply further information concerning stability and deformations at the site, we have recently request DOMES numbers for the pillars P1, P2, P3 of the ground control network: P1

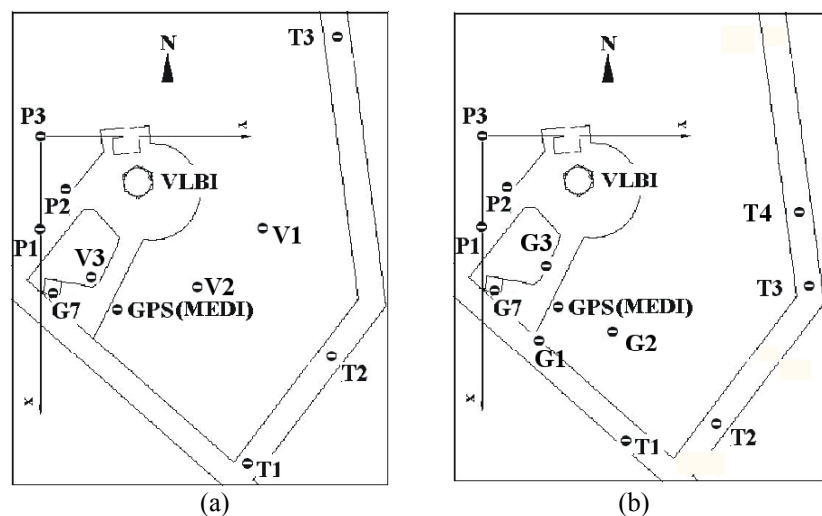


Fig. 1: Schemes of the Medicina ground control network (P are permanent concrete pillars defined by an ITRF DOMES, G7 is the height reference point, T and V are temporary points materialized by tripods). a) Ground control network used in 2001 survey, b) Ground control network of 2003 survey (G1, G2, G3 tripods used to enforce the topographic connection to the external shape of the GPS antenna).

DOMES Number: 12711M004; P2 DOMES Number: 12711M005; P3 DOMES Number: 12711M006. Sketches of local ground control points used for terrestrial measurements in 2001 survey and 2003 survey are shown in Fig. 1a and 1b, respectively.

The design of the ground control network has a remarkable impact on the correlation matrix associated to the eccentricity vector. In Fig. 1 it is possible to spot the difference between the networks of 2001 (Fig. 1a) and 2003 (Fig. 1b) surveys. In particular, in 2003 survey we have used special care in surveying the GPS antenna within the control network: we have increased the number of tripods around the GPS antenna and it has been connected with a larger redundancy and a well distributed set of observations.

2.2 Instruments and accessories

All accessories, devices and instruments used during the measurement procedure must fulfil the goal of high accuracy: in order to be effective, local ties must be determined aiming at 1 mm accuracy.

At the same time, field activities have to be planned and optimised in order to ensure short periods of VLBI antenna inactivity. Thus, modern and precise topographical instruments are fundamental tools for a quick and reliable survey.

The most common surveying techniques involved in local ties on short distances are trilateration, triangulation and spirit levelling. Our measurements were performed mainly through trilateration and triangulation.

High accuracy total stations were used, in particular Leica TD and TC series (TDA5005, TCA2003 and TC2003). These instruments fulfil the precision's requirements in terms of angular resolution (0.15 mgon) and in terms of the Electronic Distance Meter (EDM), capable of ensuring a precision of ± 1 mm on short distances (± 0.2 mm using high accuracy corner cube reflector on distances up to 120 m). The instruments are equipped with a biaxial compensator installed to correct angular readings for residual errors. We used this tool for achieving an accurate set-up of accessories (i.e. preliminary set-up of all tribrachs on markers).

Self-centring devices ensure a reliable 2-D stability. Accurate height readings are critical because of the change of instrumental height caused by different standings. We approached this problem using three-dimensional self centring devices (Fig. 2b) in order to be able to treat successive stations on the same marker as the same point of the network in the adjustment procedure: we only need to change the instrumental height, if necessary. Elevations are determined as differences with respect to a fixed vertical target installed on marker G7 (DOMES 12711M007): a special support of fixed-height (Fig. 2a) holds a retro-reflecting circular prism in a vertical position above a spirit levelling bolt.

Distances are measured using retro-reflecting prisms for all points of the local ground control network and for points installed on the VLBI antenna structures. Prisms' constants were verified in laboratory and EDM of both instruments were compared on length of common baselines.

Proper angular readings are difficult to perform on VLBI antenna structure because of the change in orientation of the targets. We therefore decided to perform angular readings at the centre of the prism: it is possible to identify the centre because there is a radial symmetry of the face edges.

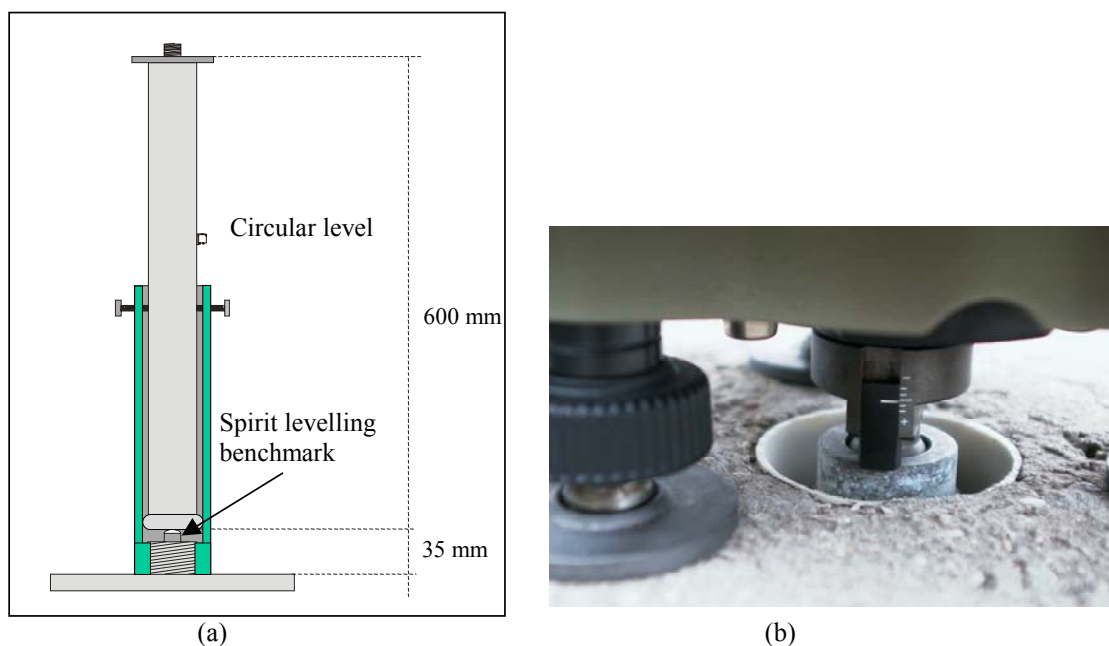


Fig. 2: Three-dimensional self-centring devices. a) System installed on a pillar of the laser pad (point G7) used as vertical reference for local surveys. b) System used for total station centring on concrete pillars and for instrumental height determination.

This operational procedure is similar in both manual and automatic collimations. As a matter of fact, during all campaigns two total stations were contemporarily employed; one of the two has an Automatic Target Recognition (ATR) capability. The ATR allows the user to automatically measure distances, horizontal and vertical angles. These measurements are quickly and easily recorded on a memory card and are taken at the centre of the circular prisms: an infrared bundle is sent from the total station and returned by the reflector, the motors turn the telescope to the centre of the light bundle and a circle reading gives the final pointing. Collimations were repeated three times in direct and reverse position of the total station thus completing three sets.

2.3 GPS Antenna Reference point surveying

The position of the GPS Antenna Reference Point (ARP) can be connected, through common observations performed from the control network, to the VLBI antenna's invariant point.

The strategy we have developed for measuring GPS choke ring antennas is based on the symmetry of its external structure. A clear and immediate advantage is related to the fact that the ARP position can be measured without removing the antenna itself. The advantage is clearly related to the operational characteristics of permanent networks for which an interruption of system functioning is an undesirable event.

The GPS ARP position can be derived triangulating points on the external structure of the GPS antenna. In particular, for each couple of points symmetrically measured with respect to the vertical axis of the antenna, it is possible to refer the averaged angular readings to a fictitious point that lies along the vertical axis (Fig. 3a). Triangulating from more than two tripods, properly distributed around the GPS antenna, it is possible to perform redundant observations for each fictitious point.

In order to obtain a reliable determination of the height of the GPS ARP, it is necessary to use the total station as a level: particular care has to be taken when installing the tripods around the GPS antenna, making sure that the instrumental reference point is approximately at the same height of the GPS ARP. The operational procedure is based on changing the instrumental height adjusting the lengths of tripod's legs and refining using the tribrach's basal screws. It is important to ensure that a 90° reading on the vertical circle corresponds to a position of the horizontal wire as close as possible to the antenna ARP (Fig. 3b).

An analogous approach can be implemented through a small spirit levelling network.

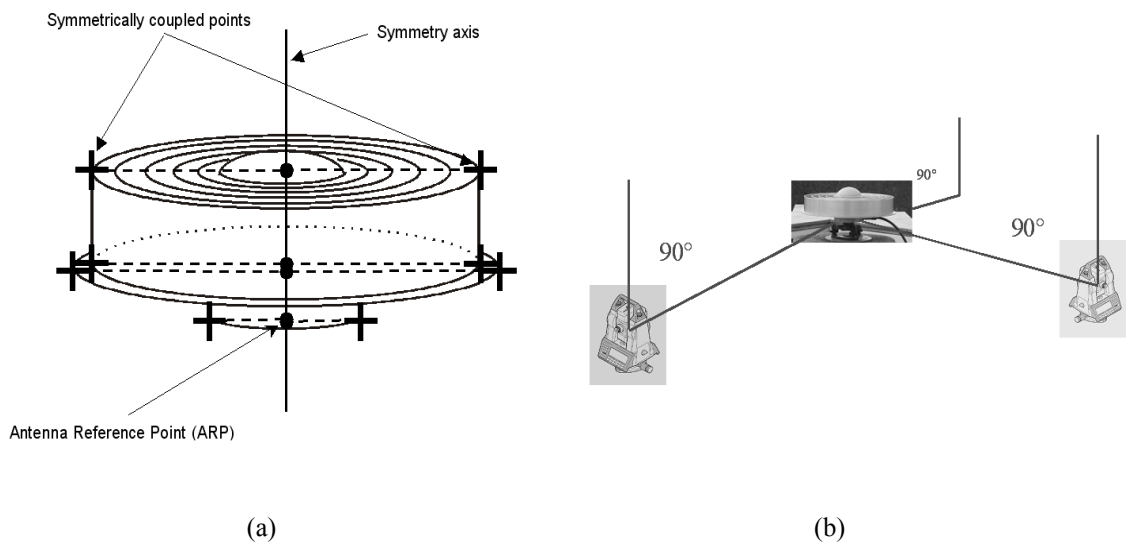


Fig. 3: a) Scheme of measured points with respect to the GPS antenna vertical axis. b) Triangulation scheme of the GPS ARP performed from tripods of the ground control network.

2.4 VLBI invariant point surveying

Several geometrical approaches can be used in order to recover the VLBI invariant point position. The strategy that we have chosen is suitable for AZ-EL telescopes: we place retro-reflecting prisms both on the lower structure (elevation fixed) and on the upper structure (elevation free) of the radiotelescope. Within a local frame, when the antenna rotates in azimuth maintaining a fixed elevation, the prisms describe horizontal circles with centres aligned along the azimuth axis of the telescope (fig. 4). In a similar manner, when the antenna moves in elevation maintaining a fixed azimuth, prisms describe circles with centres aligned along one particular position of the elevation axis (fig. 4). The invariant point is defined through these telescope axes: the Reference (Invariant) Point is the point of the azimuth (fixed) axis which has minimum distance from the elevation (moving) axis.

In order to recover the Reference Point we install ten retro-reflecting prisms on the antenna structure. According to our processing procedure it is fundamental to ensure a certain degree of symmetry around the a priori horizontal and vertical position of the sought Reference Point. This is necessary in order to take into account the presence of a possible bending or a possible skew angle which would otherwise cause a biased estimate of the Reference Point position.

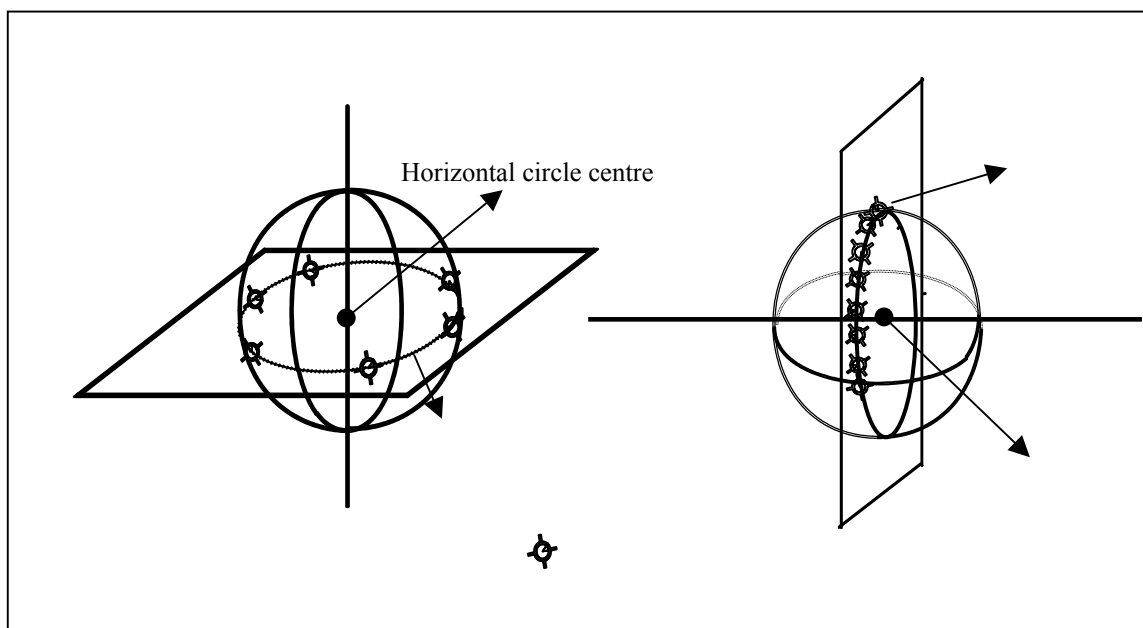


Fig. 4: Horizontal and vertical circles described by the rotation of one target around the azimuth or the elevation axis.

3 Data processing

STAR*NET least squares software has been used to perform the loosely constrained adjustment of acquired terrestrial measurements. In Figure 5 the sketch of the local ground control network used in 2002 survey is shown along with the observed points on the VLBI antenna, GPS antenna and all the measured connections. The local frame is defined fixing the horizontal coordinates of pillar P3 and the height of point G7; bearing is from point P3 to point P1. This is probably not the best way to define the local frame: its realization is affected by possible movements of ground pillars that are suggested by results obtained from 2001, 2002 and 2003 surveys and shown in Table 1. An extension of the network with pillars having a substructure of triplets of micro-poles is planned in the near future: this would considerably facilitate site monitoring and defining a good local reference frame.

A large redundancy of observations has always been sought during the surveys (see Table 2).

The adjusted positions of all targets and the complete variance covariance matrix are used in a post processing procedure that allows the rigorous estimation of the GPS-VLBI eccentricity vector along with its correlation matrix. In Table 3 the eccentricities for the three latest surveys are shown.

The SINEX file obtained from 2002 survey data is shown in the appendix. Analogous files have been produced for 2001 and 2003 surveys.

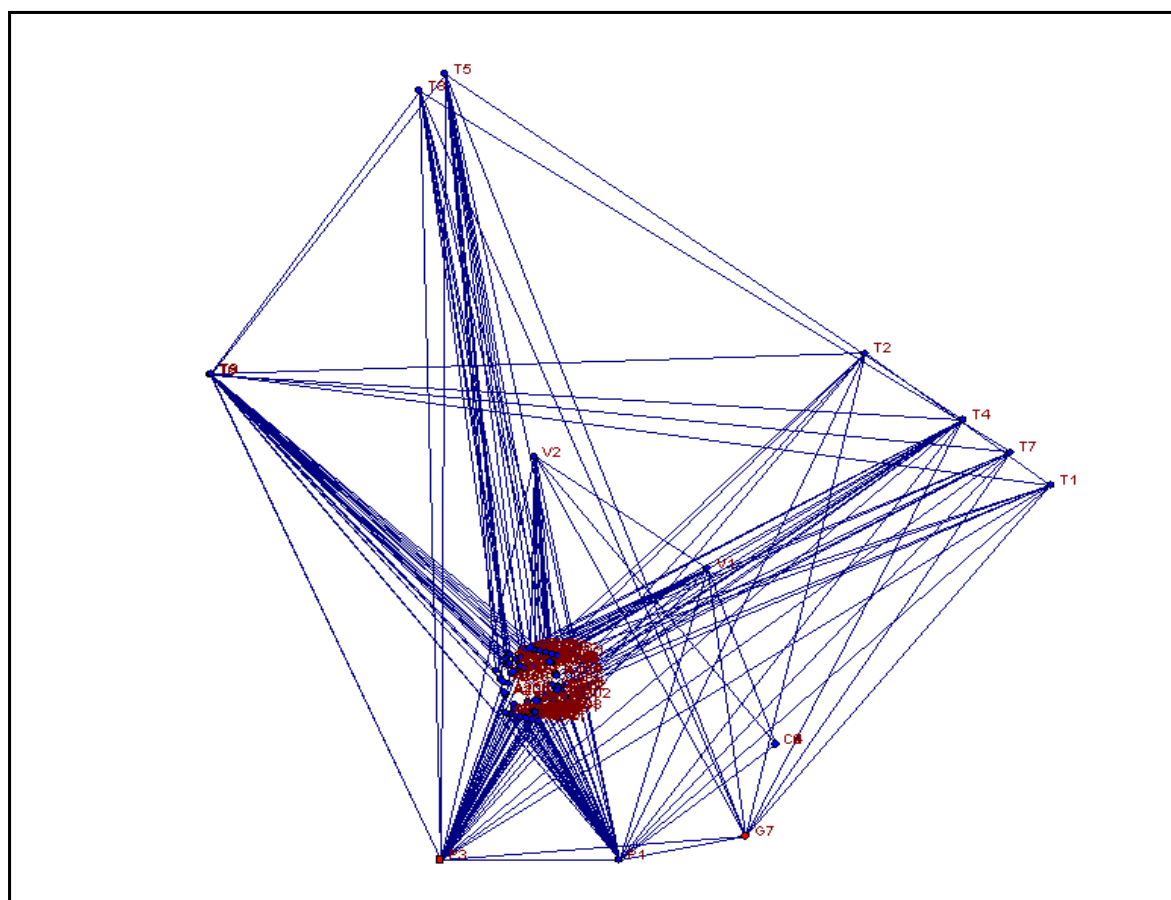


Fig. 5: Local ground control network and connections of 2002 campaign

Table 1: Local coordinates of the permanent ground control network markers

Survey	2001	2002	2003
Coordinates			
X_{p1} (m) (fixed)	0.0	0.0	0.0
Y_{p1} (m)	42.6586 ± 0.0002	42.6628 ± 0.0002	42.6636 ± 0.0002
Z_{p1} (m)	2.0772 ± 0.0003	2.0783 ± 0.0003	2.0772 ± 0.0002
X_{p3} (m) (fixed)	0.0	0.0	0.0
Y_{p3} (m) (fixed)	0.0	0.0	0.0
Z_{p3} (m)	2.0195 ± 0.0003	2.0177 ± 0.0003	2.0154 ± 0.0003
X_{G7} (m)	6.1261 ± 0.0005	6.1309 ± 0.0002	6.1386 ± 0.0003
Y_{G7} (m)	72.7897 ± 0.0006	72.7924 ± 0.0002	72.7907 ± 0.0003
Z_{G7} (m) (fixed)	0.0	0.0	0.0

Table 2: Number of observations carried-out in 2001, 2002, 2003 campaigns

	Local tie		
	2001	2002	2003
Points	110	105	236
Azimuth angles	297	308	549
Zenith angles	289	339	554
Distances	272	327	561
Unknowns	324	312	705

Table 3: Eccentricities for the 2001, 2002 and 2003 campaigns

Local tie Eccentricity	2001	2002	2003
$X_{\text{VLBI}}(\text{m})$	45.5356±0.0003	45.5360±0.0002	45.5384±0.0001
$Y_{\text{VLBI}}(\text{m})$	21.5805±0.0004	21.5825±0.0003	21.5764±0.0001
$Z_{\text{VLBI}}(\text{m})$	17.6995±0.0008	17.7024±0.0006	17.7003±0.0003
$X_{\text{GPS}}(\text{m})$	29.9692±0.0010	29.9692±0.0008	29.9848±0.0003
$Y_{\text{GPS}}(\text{m})$	79.9215±0.0011	79.9268±0.0006	79.9209±0.0003
$Z_{\text{GPS}}(\text{m})$	0.5699±0.0008	0.5701±0.0005	0.5684±0.0003

4 Conclusion

The methodology that has been developed for the GPS-VLBI eccentricity at Medicina has proved to be precise for all surveys. High precision has been the aim in all campaigns: standard deviations have decreased approximately 20% in 2003 with respect to 2002 and approximately the same amount between 2002 and 2001.

A refined survey methodology has been developed: it takes advantages of the symmetry principles that can be applied in rotational properties of VLBI antenna movements and GPS choke ring antenna features. Symmetry considerations have a major impact on the accuracy of the results: they can easily deal with the impact of bending or skew angle on the final estimate of the Reference Points.

Employing a couple of high precision total stations: three/ four days are enough to ensure a complete, redundant and rigorous local tie at Medicina.

The geometrical approach allows the computation of a full correlation matrix and consequently the production of the associated SINEX file which is the final fundamental requirement of an effective local tie.

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Appendix

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GPSR  A 12711M003
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Precision Surveys at Australian Geodetic Observatories

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1 Introduction

Precision geodetic site surveys are routinely carried out by Geoscience Australia at all of the significant co-located Australian geodetic sites to determine accurate terrestrial connections between each observing system. The terrestrial connections are the 3-dimensional vectors and their associated variance covariance information, aligned to the International Terrestrial Reference Frame (ITRF), between a primary monument and other significant reference marks at each site. These co-located geodetic observing sites in Australia (see Fig. 1 and 2) include:

- Yaragadee (SLR/GPS/DORIS/GLONASS/Absolute-Gravity);
- Mount Stromlo (SLR/GPS/ DORIS/GLONASS);
- Orroral (SLR now obsolete, was 27km from Tidbinbilla);
- Hobart (VLBI/GPS/Absolute-Gravity);
- Tidbinbilla. (VLBI/GPS);
- Darwin (GPS/GLONASS);
- Davis, Antarctica (GPS/GLONASS/Tide-Gauge).

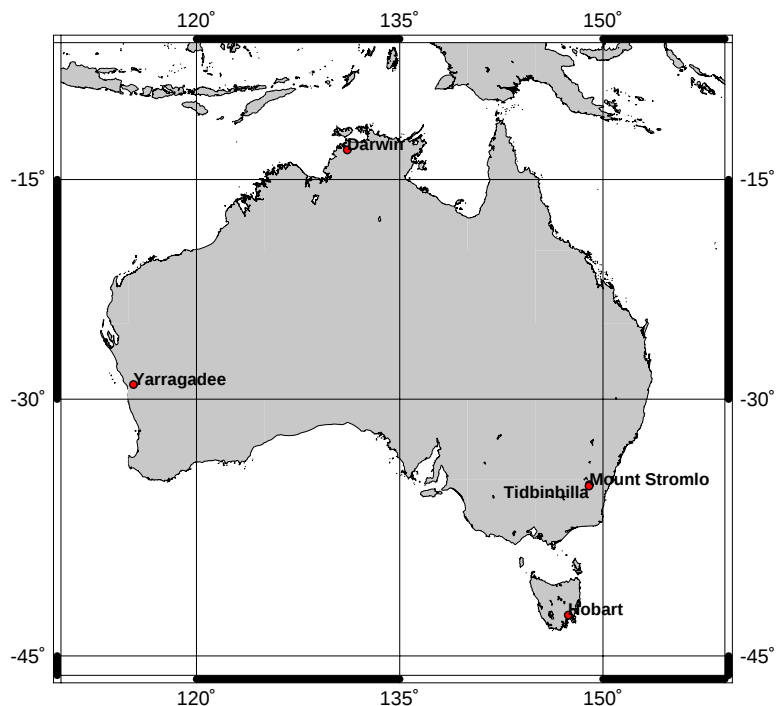


Figure 1: Co-located Geodetic Sites, Australia.



Figure 2: Co-located Geodetic Sites, Australia. Top Left Yaragadee. Top Right Mount Stromlo. Centre Hobart. Bottom Tidbinbilla.



The Geoscience Australia terrestrial survey connection between observing systems at each of these sites are generally determined using a combination of GPS, total station and precise levelling observations.

While not directly related to co-location for terrestrial reference development Geoscience Australia is also involved in the site survey of a number of GPS to tide gauge connections in Australia and the region. These include Hillarys in Western Australia, Burnie in Tasmania, Macquarie Island and Mawson, Casey, Davis in the Australian Antarctic Territory. In addition Geoscience Australia through the Australia Agency for International Development (AUSAID), is involved in the site survey of a number of GPS to tide gauge connections throughout the South Pacific including stations at Samoa, Cook Islands, Fiji, Tuvalu, Tonga, Manus Island, PNG, Kiribati, Vanuatu, Nauru and Micronesia, see Fig. 3. With further stations planned for Marshall Islands, Palau, Niue, and the Solomon Islands. Tide gauge connections include multi-day GPS connection between GPS Station and the Tide Gauge Bench Mark (TGBM); an orthometric levelling connection as well using Total Station Levelling (TSL).

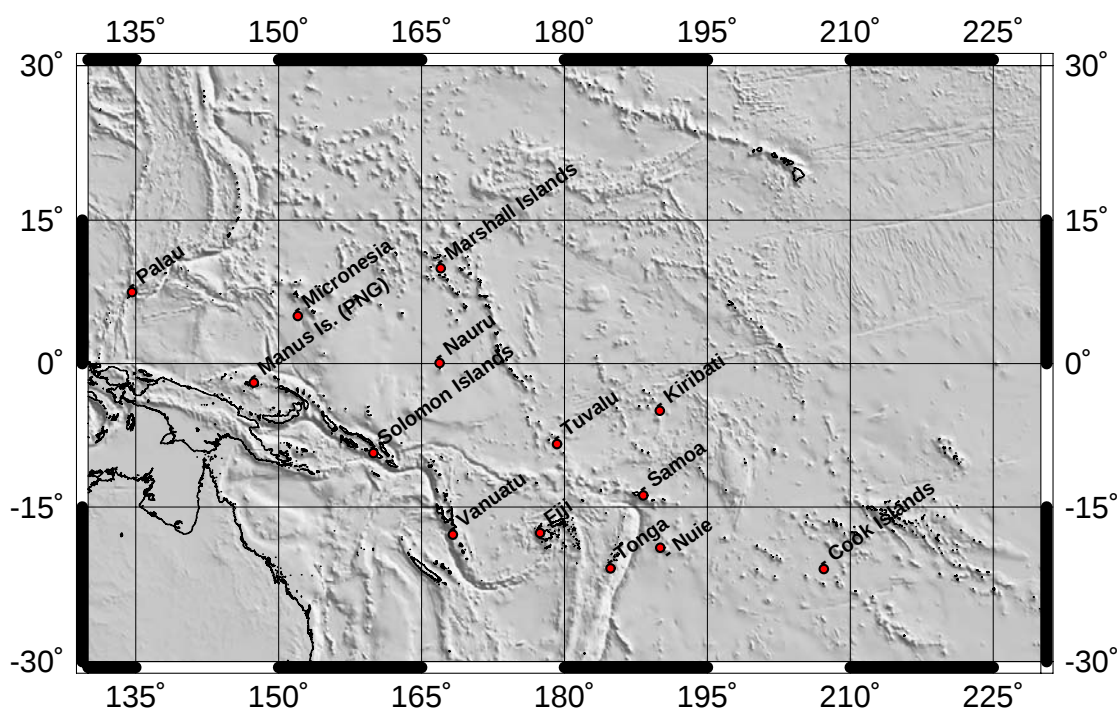


Figure 3: South Pacific Sea Level and Climate Monitoring Project GPS Network.

2 Planning and Strategies

The survey of precise geodetic facilities should

- Be timed for optimum survey observations, i.e. timing the survey when weather conditions are neutral to minimise atmospheric effects;
- Allow for several days down time, particularly on Satellite Laser Ranging (SLR) or Very Long Baseline Interferometry (VLBI) systems;
- Be planned to avoid critical tracking campaigns;

- Plan the placement of marks on the telescope/antenna to optimise observations for the determination of axes (in the case of indirect reference point determination), i.e. optimise the target trajectories and the radius of the trajectories; and
- Place instrument stand-points to satisfy survey accuracy demands (as determined by network simulation if necessary).

Forced centring is used to eliminate the introduction of setup errors wherever possible. A Leica Zenith Nadir precise optical plummet is used for all tripod setups, to ensure near zero plumbing errors. Additionally, wherever possible concrete pillars are used for instrument standpoints. This ensures setup stability during the often long observation periods when observations are taken to the antenna or telescope systems.

3 Equipment and Equipment Calibration

Geoscience Australia primarily uses a Leica TCA2003 (total station) for precision surveys, see Fig. 4. This instrument has an angular measurement (horizontal and vertical) precision specification of 1 second of arc and a distance measurement precision specification of 1 mm plus 1 part per million. However a laboratory calibration revealed that the specifications were somewhat pessimistic and the actual precision were angular measurement (horizontal and vertical) precision of 0.6 second of arc and a distance measurement precision of 0.5 mm plus 0.4 part per million. The use of motorization and automatic target recognition (ATR) in the Leica TCA2003 reduces observer errors. Geoscience Australia uses Leica precision prisms with Tribrach and carriers (including plate bubble) and a zenith nadir plummet for centring tripods where they are required; a fixed height prism pole (see Fig. 5) for Total Station Levelling (TSL) and a invar staff for instrument heighting.



Figure 4: Left Leica TCA2003 Total Station. Right Leica Precision prisms with Tribrach and carriers (including plate bubble).



Figure 5: Fixed height prism pole for Total Station Levelling (TSL).

Geoscience Australia's Leica TCA2003 (total station) was purchased with the factory calibration option. In addition an annual comparison with a standard baseline (linked to the Australian National Standard) is made. At the time of survey internal angular calibrations are estimated. The calibration of prism / reflectors is made following the standard methodology over a calibration baseline. Comparison with GPS is also undertaken. The invar staff used was factory calibrated initially (when purchased) and is calibrated biennially.

4 Monumentation and Network Design

The choice of station monumentation is highly dependant on site conditions, however,

- Ideally instrument standpoints are stable bedrock anchored pillars;
- Pillars should have reference marks to monitor local deformation; and
- Survey marks should have an unambiguous reference point.

Ideally the survey network design should link instrumentation through a highly over determined braced quadrilateral network design. For SLR and VLBI systems with reference points unable to be directly observed Geoscience Australia uses an approach for estimating the observation reference point using an indirect technique of coordinating targets on the measurement systems during specific rotational sequences of the observing system. The axes of rotation are then used to define the reference point of the instruments.

In the case of GPS antennas the Antenna Reference Point (ARP) of the GPS is coordinated directly, see Fig 6. While for DORIS antennas direction observations are made symmetrically to each side of the antenna case then averaged and intersected with further observations made from at least one other standpoint.

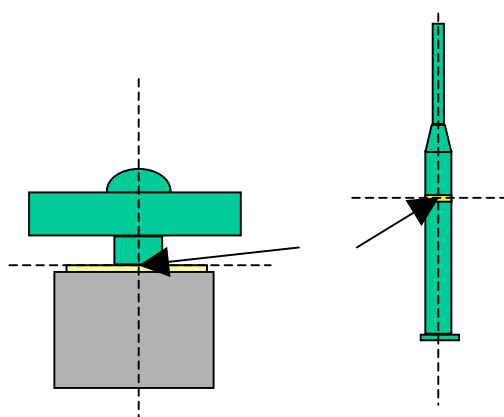


Figure 6: Reference point of GPS and DORIS.

5 Additional Issues

The accurate measurement of observing instrument trunnion axis height has been addressed by the use of observational sequences to a level staff (Rueger and Brunner, 1981) situated on a bench mark of known height. In surveys to date poor performance of the tape reflectors on distance and angular measurement have become apparent and their use is no longer recommended for high precision surveys. Another effect yet to be fully quantified is the unknown effect of refraction on lines which have a temperature gradient. In the future the potential use of laser scanning or terrestrial photogrammetry to determine VLBI antenna deformation will be explored.

6 Final Comments

Precision surveys are currently undertaken at the one millimetre level although monument design and stability remain an issue. Repeat surveys are completed every two years to monitor network and system stability.

References

Rueger J.M., and Brunner F.K., *The Australian Surveyor*, June 1981, Vol. 30, No. 6.

The 2002 Local Tie Survey at the Onsala Space Observatory

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Abstract. We describe the local tie survey work performed at the Onsala Space Observatory in the year 2002. Classical geodetic measurements and measurements with the Global Positioning System (GPS) were used to determine the local tie between the reference points at Onsala that are relevant for the International VLBI Service for Geodesy and Astronomy (IVS) and the International GPS Service (IGS) in a local and a global reference frame. The new local tie information together with the corresponding covariance information is available in SINEX format.

1 Introduction

The Onsala Space Observatory has been active in space geodesy since more than 30 years (Scherneck et al., 1998). The first geodetic Very Long Baseline Interferometry (VLBI) experiment at Onsala was already performed in the spring of 1968 (Whitney, 1974). At this time, the 25.6 m radio telescope was used for geodetic VLBI. Later, the radome enclosed 20 m telescope at Onsala was constructed and during a transition period both telescopes were used for geodetic VLBI observations, observing in parallel but separately on X- and S-band. Mark-III geodetic VLBI observations started in 1979 and since 1987 both frequency bands are observed with the 20 m telescope. GPS equipment was installed at Onsala in the 1980ies. Onsala became a CIGNET (Cooperative International GPS Network) station in 1987. A monument for a GPS antenna was constructed and acts today as reference monument for the Swedish ground-based GPS network SWEPOS and the IGS.



Figure 1: Equipment for space geodetic observations at the Onsala Space Observatory. Left: The radome enclosed 20 m radio telescope used for geodetic VLBI (IVS monument). Right: The permanently installed and radome equipped antenna used with Global Navigation Satellite Systems (GNSS) (IGS monument). The two monuments are located within about 80 m distance.

Figure 1 shows the two monuments at Onsala that are relevant for the IVS and the IGS. These are the radome enclosed 20 m telescope and the permanently installed GPS antenna, located in about 80 m distance from each other. The two international services IVS and IGS are important for the establishment and preservation of the International Terrestrial Reference Frame (ITRF) (Altamimi et al., 2001). For the comparison and combination of IVS and IGS products, it is necessary to know the so-called local tie, the exact relative position of the reference points of the corresponding monuments (e.g. Long and Bosworth, 2000).

Classical geodetic measurements and several GPS campaigns were performed in the 90ies of the last century in order to establish the local tie between the reference points at the observatory (Peterson, 1991; Johansson et al., 1992). However, for these local tie realizations, some distances in the 20 m telescope were taken from construction drawings. Furthermore, the covariance information of the local tie was not provided. When the mobile VLBI telescope MV-2 visited Onsala, a short baseline VLBI experiment was performed to determine the local tie (Potash, 1992). Also this local tie realization suffered from a lack of complete covariance information. Lidberg et al. (2003) give an overview on the history of local tie measurements at Onsala.

Since the earlier local tie information show some deficiencies, we performed a new local tie survey at the Onsala Space Observatory in the year 2002 using classical geodetic methods and GPS observations. The goal of this survey was to determine the local tie information in a local and a global reference frame with high accuracy, including the complete covariance information.

2 Special local tie difficulties at the Onsala Space Observatory

The special difficulties at Onsala are that the IVS and IGS reference points are not easily accessible and observable, see Figure 2. In general, the space geodetic reference point of azimuth-elevation radio telescopes used for VLBI is defined as the intersection of the telescopes's azimuth and elevation axes. In case these axes do not intersect, the reference is defined as the point on the azimuth axis that is closest to the elevation axis. At the Onsala 20 m telescope, the reference point does not exist as a material but is located somewhere inside the telescope receiver cabin. It thus can only be determined with indirect surveying methods. Furthermore, the telescope is surrounded by an optically opaque radome. Thus, direct observations of any part of the telescope are not possible from the survey points of the observatory's local geodetic network outside the radome building.

The IGS reference point is a steel bolt installed in solid bedrock below the GPS-antenna which is installed permanently on a concrete pillar. Thus, this steel bolt is hardly observable with survey equipment. It is only possible to observe it by viewing through two small openings in the walls of the concrete pillar that are oriented perpendicularly to each other.

3 The project strategy

The project strategy was to perform classical geodetic survey measurements of the telescope's reference point using an indirect survey method, to perform a classical geodetic survey of the local survey network and the IGS reference point, and to perform GPS observations in the local network (Eschelbach, 2002; Eschelbach and Haas, 2003).

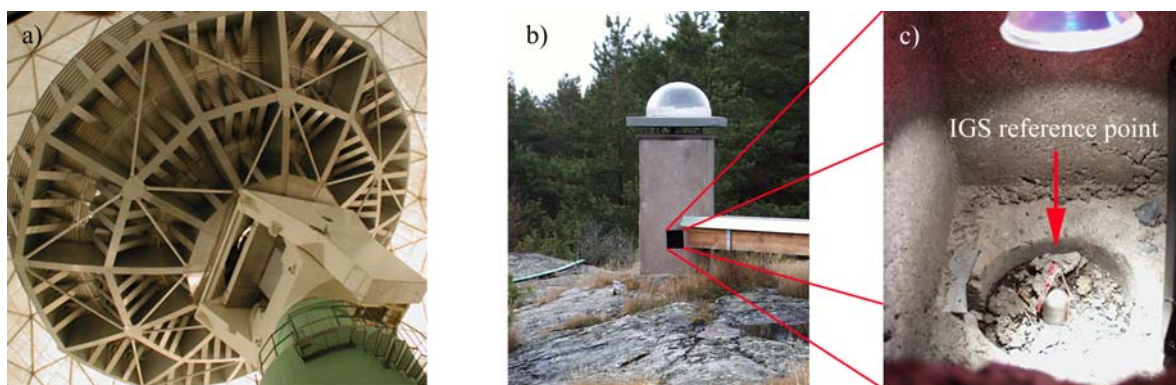


Figure 2: IVS and IGS reference points at Onsala: a) view inside the radome enclosing the 20 m radio telescope. The telescope's space geodetic reference point is the physically non-existing intersection of the telescope's azimuth and elevation axes; b) the IGS monument from the outside; c) zoom-in into the inside of the IGS monument showing the marker in solid bedrock which is the IGS reference point.

To make the necessary measurements possible, five new survey pillars inside the telescope radome and a number of new ground markers inside and outside the radome building were installed. The new survey pillars should allow the survey of the telescope in order to determine its reference point with indirect methods. They were installed on top of the radome foundation wall to allow observations of the telescope with reasonable zenith distances of about 40 gon. The new ground markers should allow a connection of the new survey pillars to the existing local survey network at the observatory. Views through opened doors and windows should allow a connection between markers inside and outside the radome building. Some of the new ground markers that were installed outside of the radome building should also be used for GPS measurements. Figure 3 shows examples of the new survey pillars and ground markers. Figure 4 shows drawings of the local survey network and its extensions by new survey pillars and ground markers.

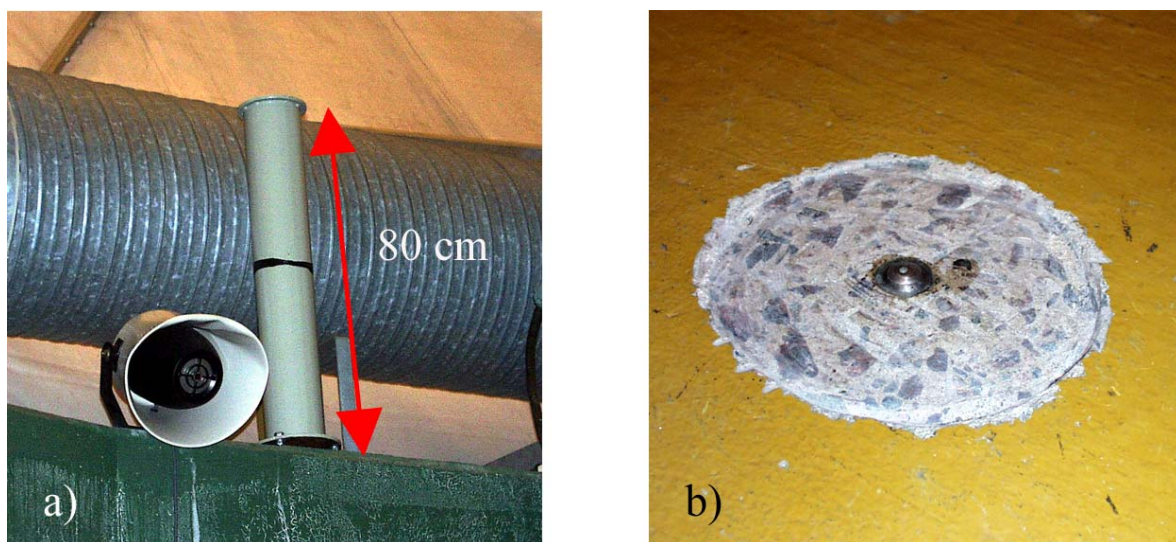


Figure 3: a) example of a new survey pillar installed on the radome foundation wall in about 3 m height; b) example of a new ground marker.

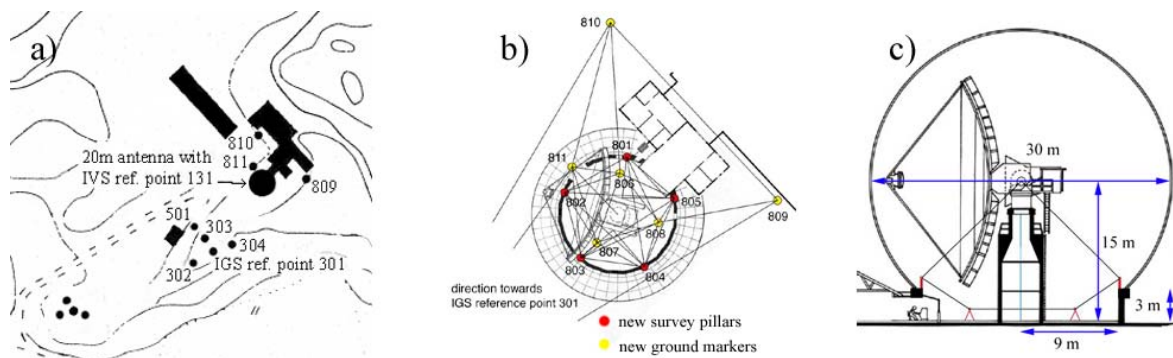


Figure 4: a) map of the local survey network at the Onsala Space Observatory, extended by the new ground survey markers 809, 810 and 811; b) drawing of the radome building showing the new survey pillars and ground markers; c) cross-section through the radome building showing the telescope, and the new survey pillars and ground markers.

4 Measurements

The first and most time consuming part of the project was to perform the measurements inside the radome building in order to be able to determine the telescope's reference point. The second part of the project was the measurement of the local network, including the connection of the new markers and survey pillars and the survey of the IGS reference point. The last part of the project included the GPS-observations on several markers in the local network. All details on the measurements are described in Eschelbach (2002) and Eschelbach and Haas (2003).

4.1 Telescope measurements

Since the telescope's reference point at Onsala is not directly observable, an indirect survey method had to be used for its determination. The idea was to survey the endpoints of the elevation axis when the telescope was positioned to different azimuth directions in order to be able to determine the reference point in a following step. However, the endpoints of the elevation axis are not directly observable either at Onsala. Thus, to determine these endpoints, additional survey markers were installed on the telescope cabin that could be observed from the five new survey pillars on the radome foundation. For the Epoch-1 survey, in total eight survey markers were installed in a distance of some decimeters from the elevation axis on both sides of the telescope cabin. Observation of four of these markers, two on each side, under different elevation positions of the telescope should allow the determination the elevation axis endpoints by fitting 3D-circles. For the Epoch-2 survey, magnetic survey markers were installed on both sides of the telescope cabin that should act as synthetic elevation axis endpoints. Figure 5 shows the survey markers used for the Epoch-1 and Epoch-2 measurements.

The survey markers were observed from baselines formed by pairs of the new survey pillars for different elevation and azimuth positions of the telescope (Epoch-1), respectively different azimuth positions (Epoch-2). For Epoch-1 a total number of about 600 new points was observed. Survey instruments of type Leica T2002 and a Leica TCR1102 were used for these measurements. The measurement procedure and all details on the Epoch-1 and Epoch-2 measurements are described in Eschelbach (2002) and Eschelbach and Haas (2003).

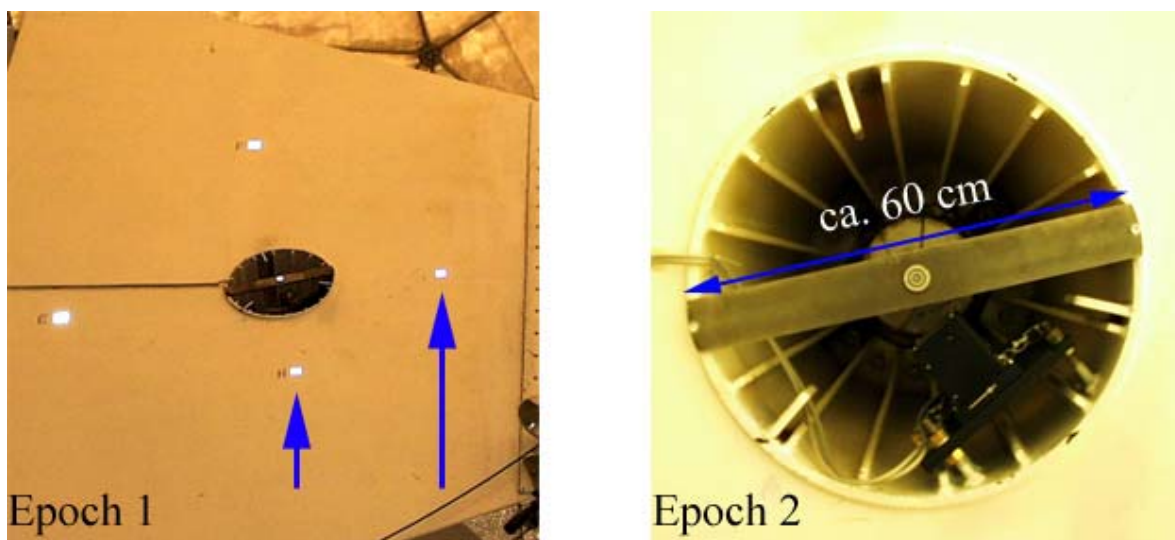


Figure 5: Survey markers on one side of the telescope cabin: markers used for the Epoch-1 measurements (left, marked with arrows) and the synthetic endpoint of the elevation axis (magnetic marker in the centre) used for the Epoch-2 measurements (right).

The observational data were analysed with the network adjustment program Netz3D (Jäger, 1995). The mean position error of the new points at the telescope was below 0.2 mm. These coordinates were used in a further step to derive the elevation axis endpoints and the telescope's reference point by three dimensional circle fits (Eschelbach, 2002; Eschelbach and Haas, 2003).

4.2 Measurements of the local network and IGS reference point

The new survey pillars were connected to the local network at the observatory. Additionally, the IGS reference point was connected to the local network. The observations included horizontal direction measurements with a Leica T2002 instrument, horizontal distance measurements with a Leica TCR1102 instrument, and digital levelling with a Zeiss DINI 10 instrument. The observational data were analysed with the Netz2D software (Jäger et al., 1996). Mean accuracies of 0.2 mm for the horizontal position and 0.1 mm for the vertical position were achieved. Due to the difficult observation situation at the IGS reference point, its vertical component was determined with a standard deviation of 0.6 mm only. Details on the measurements and analysis can be found in Eschelbach (2002) and Eschelbach and Haas (2003).

4.3 GPS-observations in the local network

GPS-observations on four ground markers of the local network were performed for a total of 55 days. The data were analysed together with data from the IGS station using the GPS analysis software package Bernese version 4.2 (Hugentobler, et al., 2001). The coordinates of the markers in the local network were determined from a L1-only solution. The achieved repeatabilities were on the order of 0.6 mm and 1.0 mm for the horizontal components, and 1.7 mm for the vertical component. Some details on the GPS-measurements and the corresponding data analysis can be found in Eschelbach and Haas (2003).

5 Data analysis and results for the local tie

For each azimuth position, the telescope markers observed in Epoch-1 for different elevation positions describe quarter circles around the elevation axis endpoints. One-step 3D-circle fits were applied to determine the elevation axis endpoints and their complete covariance information. The in this way determined endpoints of Epoch-1 and also the directly observed synthetic endpoints of Epoch-2 describe horizontal 3D-circles around the azimuth axis when the telescope is moved in azimuth. Thus, one-step 3D-circle fits to the elevation axis endpoints resulted in coordinates for the telescope's reference point. Details on the 3D-circle fits and the data analysis are given in Eschelbach (2002) and Eschelbach and Haas (2003). Thermal deformation of the concrete telescope tower and the radome foundation were taken into account in the data analysis so that all results refer to a temperature of 0° Celsius. As an example, Figure 6 shows the relative vertical height measurements of the concrete telescope tower as observed with the invar rod measurements system installed at the Onsala 20 m telescope (Johansson et al., 1996). The coordinates of the reference point in the local reference frame were derived with standard deviations on the order of 0.1 mm in all three components for Epoch-1 and 0.1 mm for the horizontal components and 0.3 mm for the vertical component in Epoch-2. The coordinates of the reference point agree between the two epochs within their formal error bars.

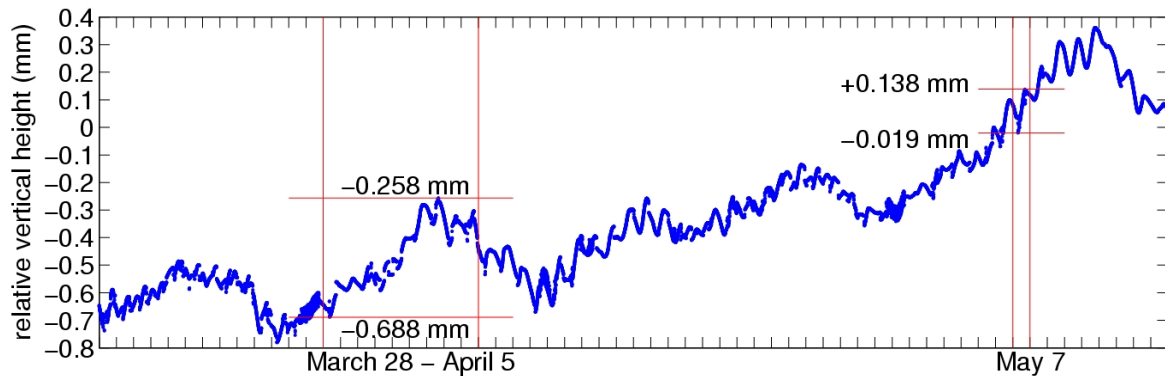


Figure 6: Relative vertical height of the concrete telescope tower as measured with the invar rod measuring system. Epoch-1 was observed between March 28 and April 5, 2002, and Epoch-2 on May 7, 2002.

The coordinates of the reference points were transformed to ITRF using a Helmert transformation with four identical points in the local network that had coordinates given in both frames. The mean residual of the transformation was 0.8 mm. Table 1 lists the coordinates for the IGS and IVS reference points in both reference frames. Table 2 gives the local tie as a SINEX-file including the complete covariance information.

Table 1: Coordinates of the IGS- and the IVS-reference points and their standard deviations

Local reference frame	x [m]	σ_x [mm]	y [m]	σ_y [mm]	z [m]	σ_z [mm]
IGS 301	12.7535	± 0.2	23.3877	± 0.2	9.0455	± 0.6
IVS 311	90.1237	± 0.1	35.9493	± 0.1	22.7594	± 0.1
ITRF	X [m]	σ_X [mm]	Y [m]	σ_Y [mm]	Z [m]	σ_Z [mm]
IGS 301	3370658.5879	± 0.3	711877.1097	± 0.2	5349786.9288	± 0.5
IVS 311	3370605.9602	± 0.1	711917.5650	± 0.1	5349830.8018	± 0.1

Table 2: SINEX file with the local tie information for the Onsala Space Observatory

```

%=SNX 1.00 GIK 03:176:00000 GIK 02:127:00000 02:193:00000 C 00006 2 X
*-----
+FILE/COMMENT
* File created on June 25, 2003
* CONTACT eschelbach@gik.uni-karlsruhe.de
-FILE/COMMENT
*-----
+SITE/ID
*CODE PT DOMES T STATION DESCRIPTION APPROX_LON APPROX_LAT APP_H
ONSG A 10402M004 Onsala 301 57 23 43.1 11 55 31.9 45.543
ONSV A 10402M006 VLBI 7211 57 23 45.0 11 55 34.9 59.254
-SITE/ID
*-----
+SOLUTION/ESTIMATE
*INDEX TYPE CODE PT SOLN_REF_EPOCH UNIT S ESTIMATED VALUE STD_DEV
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2 STAY ONSG A 1 02:193:00000 m 2 .7118771097 0000E-06 .18811E-03
3 STAZ ONSG A 1 02:193:00000 m 2 .534978692880000E-07 .51152E-03
4 STAX ONSV A 1 02:193:00000 m 2 .337060596020000E-07 .99995E-04
5 STAY ONSV A 1 02:193:00000 m 2 .7119175650 0000E-06 .99995E-04
6 STAZ ONSV A 1 02:193:00000 m 2 .534983080180000E-07 .99995E-04
-SOLUTION/ESTIMATE
*-----
+SOLUTION/MATRIX_ESTIMATE L COVA
*PARA1 PARA2 PARA2+0 PARA2+1 PARA2+2
1 1 .1178080000000000E-06
2 1 .1353900000000000E-07 .3538600000000000E-07
3 1 .1497740000000000E-06 .3442000000000000E-07 .2616550000000000E-06
4 1 .0000000000000000E+00 .0000000000000000E+00 .0000000000000000E+00
4 4 .9999000000000000E-08
5 1 .0000000000000000E+00 .0000000000000000E+00 .0000000000000000E+00
5 4 .0000000000000000E+00 .9999000000000000E-08
6 1 .0000000000000000E+00 .0000000000000000E+00 .0000000000000000E+00
6 4 .0000000000000000E+00 .0000000000000000E+00 .9999000000000000E-08
-SOLUTION/MATRIX_ESTIMATE L COVA
%ENDSNX

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6 Results concerning the telescope geometry

The performed measurements allowed to derive more information concerning the telescope geometry than just the telescope's reference point. By an analysis of the vertical height of the elevation axis endpoints as a function of azimuth position of the telescope, the divergence of the telescope's azimuth axis from the local vertical could be determined. The results show, that the adjustment of the telescope balance weights that was performed between the Epoch-1 and the Epoch-2 measurements reduced the divergence from the local vertical considerably. The analysis of the mean difference between elevation axis endpoints at opposite sides of the telescope cabin also allowed to derive a value for the non-orthogonality between the azimuth and elevation axes. Furthermore, since the Epoch-2 measurements included observations of 10 pairs of diametral elevation axis endpoints, these measurements allowed to determine the telescope's axes offset. All details on these results concerning telescope geometry are given in Eschelbach (2002) and Eschelbach and Haas (2003). The results are summarized in Table 3. Note that the sign of the axes offset in Eschelbach (2002) and Eschelbach and Haas (2003) is wrong.

Table 3: Results concerning the telescope geometry

Parameter	Measurements	Value
Divergence of the azimuth axis from the local vertical.	Epoch-1	21 ± 6 arc-seconds
Divergence of the azimuth axis from the local vertical.	Epoch-2	13 ± 6 arc-seconds
Non-orthogonality of azimuth and elevation axis.	Epoch-1	40 ± 8 arc-seconds
Axes offset.	Epoch-2	-6.0 ± 0.4 mm

7 Conclusions and outlook

The local tie survey performed at the Onsala Space Observatory in the year 2002 was very successful. The IVS reference point was determined with a standard deviation in three dimensions of about 0.25 mm in the local reference frame. The three-dimensional local tie between the IVS and IGS reference points was determined on the sub-mm level in both the local and the global reference frame. During the analysis the thermal deformation of the telescope tower and the radome foundation has been corrected for so that this local tie refers to a temperature of 0° Celsius. The complete covariance information was preserved in this real 3D-determination of the reference points and the local tie and the complete local tie information is available in SINEX format. Besides the pure local tie information, several previously unknown geometrical properties of the radio telescope have been determined, too. An axes offset of $-6.0 \text{ mm} \pm 0.4 \text{ mm}$ has been detected which should be used in the analysis of geodetic VLBI data. So far in the VLBI data analysis it was assumed that the axes offset was zero at the 20 m telescope. A repeated local tie survey in a couple of years is highly desirable to investigate whether the local tie and the telescope geometry are changing over time.

Acknowledgements

This project was a cooperation of the Onsala Space Observatory, Chalmers University of Technology and the Geodetic Institute of the University of Karlsruhe. We would like to thank the employees of the Geodetic Institute for their advisory support and the staff of the Onsala Space Observatory and in particular the members of the Space Geodesy and Geodynamics Group at the Onsala Space Observatory for their active support during the measurements.

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Local Ties Between the Reference Points at the Fundamentalstation Wettzell

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Summary. The local ties between reference points of the geodetic space observation systems and the geodetic local network markers have been derived through terrestrial local survey and GPS observations. The local survey consists of direction, distance and levelling observations, which were analysed with the adjustment program PANDA. GPS observations were carried out for the orientation of the local network within the global reference frame. The GPS observations were analysed using the Bernese GPS Software. Both results were combined by making use of the Bernese GPS Software. The results finally were made available in the SINEX format for further application.

1 General Information

Local Ties between the reference points of the observing systems co-located at a Fundamentalstation are fundamental for combining the different space techniques. The Fundamentalstation Wettzell, operated by the Bundesamt für Kartographie und Geodäsie in collaboration with the Forschungseinrichtung Satellitengeodäsie of the Technische Universität München, is equipped with

- a 20m Radiotelescope for VLBI
- a Laser Ranging System WLRs for SLR with capabilities for LLR
- various GPS and GLONASS receivers
- a DORIS station

Various local surveys have been carried out since the existing of the station Wettzell in order to determine the local ties, to detect local motions or to demonstrate the local stability.

In the period from 2000 to 2004 various observations have been conducted to control and improve the local ties with highest accuracy through terrestrial survey and local GPS observations for the orientation of the local network. Needs for the new survey came up to include control points for the Ringlaser G, which has started operation in 2002.

2 Local Network

The local control network has an extension of 250m x 180m and consists of 50 marked points and 113 levelling points. Figure 1 gives an overview of the entire network. Most of the points are marked as stable survey pillars, Figure 2, with forced centering capabilities or as stable ground markers. Additional levelling points are installed for height control. Levelling technique can easily be employed for regular survey in order to monitor local stability.

As not all the points are of general interest, this report concentrates only to those points used for the combination of the employed space techniques. Table 1 gives the point description with the internal station number, the DOMES number and the approximate longitude, latitude and height.

Table 1: Description of local survey points, relevant for combination of space techniques

Site ID	DOMES No.	Station Description	APPROX_LON	APPROX_LAT	APP_H
1	M	Pillar 1	12 52 39.1	49 8 42.8	658.9
100	M	TIGO VLBI Wettzell	12 52 39.4	49 8 40.2	657.5
200	M	TIGO SLR Wettzell	12 52 38.1	49 8 39.4	657.2
7224	14201S004	VLBI reference point	12 52 38.8	49 8 42.0	669.1
7595	M	Platform	12 52 43.0	49 8 40.4	658.1
7596	14201M004	Platform	12 52 43.3	49 8 39.0	658.6
7597	14201M005	Platform; DORIS	12 52 42.5	49 8 38.3	660.3
7598	M	Platform	12 52 41.9	49 8 39.5	660.6
8834	14201S018	SLR reference point	12 52 40.8	49 8 39.9	665.4
1201	14201M011	WTZT GPS	12 52 44.2	49 8 39.2	665.9
1202	14201M010	WTZR GPS	12 52 44.1	49 8 39.1	666.0
1203	14201M012	WTZJ GPS/GLONASS	12 52 44.2	49 8 39.1	665.9
1204	14201M013	WTZA GPS	12 52 44.0	49 8 39.2	665.9
1205	14201M014	WTZZ GPS	12 52 44.1	49 8 39.2	665.9
1206	M	WTZL GPS	12 52 44.1	49 8 39.2	665.9

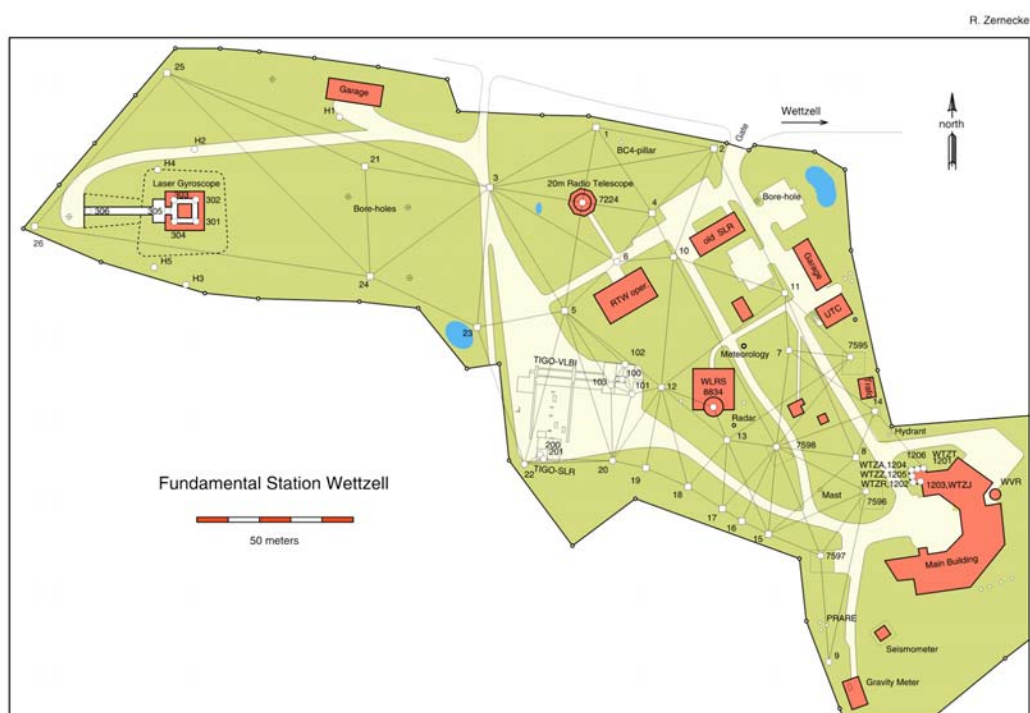


Figure 1: Local Network of the Fundamental Station Wettzell



Figure 2: Survey pillar of the local network, top view of the pillar with survey marker for force centering and marker for levelling

3 Local terrestrial survey observations

The analysis of the local terrestrial survey is based on observations performed in the period from 2000 to 2002. Observations carried out in 2000 and 2001 by Rudolf Zerneck placed emphasis to include the reference points of the ring Laser into the local survey network [1], [2], [3]. Control observations covering the entire network including the reference points of the geodetic space systems were carried out by Karin Fischer and Svetlana Becker in the frame of their thesis [4].

For

- distance measurements a Mekometer ME5000 (precision: $0.2\text{mm} + 0.2\text{ppm}$), and Geodimeter 600 (precision $1\text{mm} + 1\text{ppm}$)
- direction measurements theodolites and Tachymeters as T3000 and TDA 5005 (precision 0.15mgon) and TCA 2003 (precision 0.3mgon)
- levelling DINI11 and NI2 (precision 0.3mm/km)

were employed.

4 3D adjustment of the terrestrial local network

The adjustment of the network has been done with the “PANDA” program [5]. The network specific parameters of the adjustment are summarized in table 2.

Table 2: Network specific parameters of the PANDA free network solution

total number of observations :	1014
number of directions :	392
number of distances :	457
number of height differences :	165
total networkpoints :	52
number of datum points :	27
number of unknowns :	156
additional parameter estimated :	1
unknown number for orientation :	54
free network parameter:	4
degrees of freedom :	807

The precision obtained for all network points is shown in Figure 3, and demonstrated by the error ellipses for the location and error bars for height. The goal was to derive local ties better than 1 mm, which is achieved for the entire network. Larger values occur for some border points. All ties being relevant for the combination of the space techniques show a precision better than 0.3mm.

5 GPS observations and analysis

During two campaigns dedicated GPS observations were carried out in order to connect the local network to the global reference frame ITRF. The first campaign was from May 31 to June 04, 2000 to include the ring Laser reference points into the local survey network. Beside the four permanent observing GPS stations four temporary sites were occupied additionally (Figure 4).

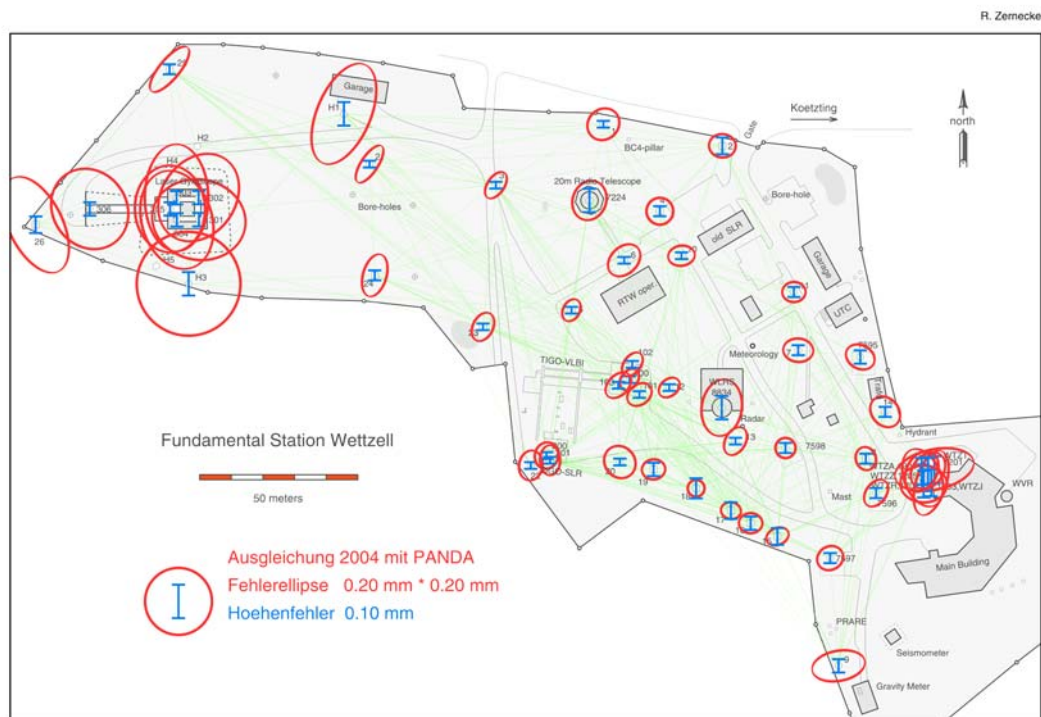


Figure 3: Accuracy obtained after the adjustment, demonstrated by the error ellipses

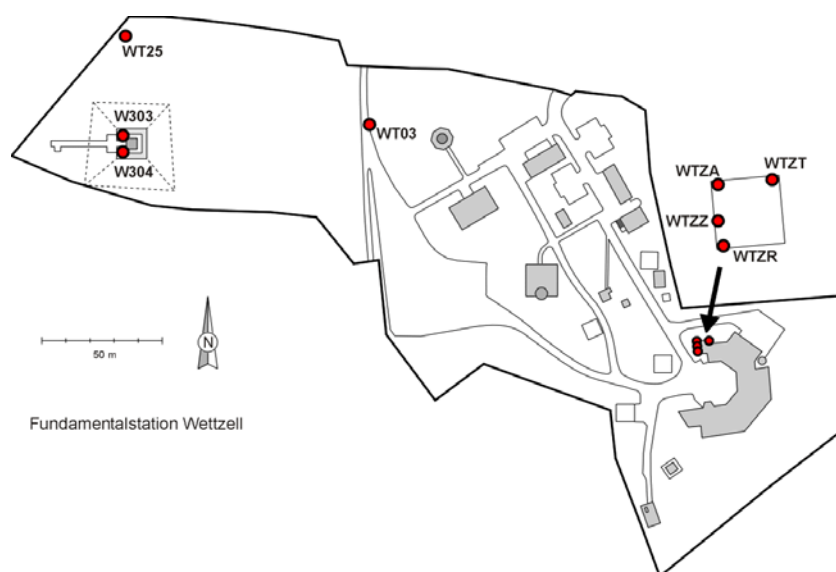


Figure 4: GPS observations during May 31 to June 4, 2000

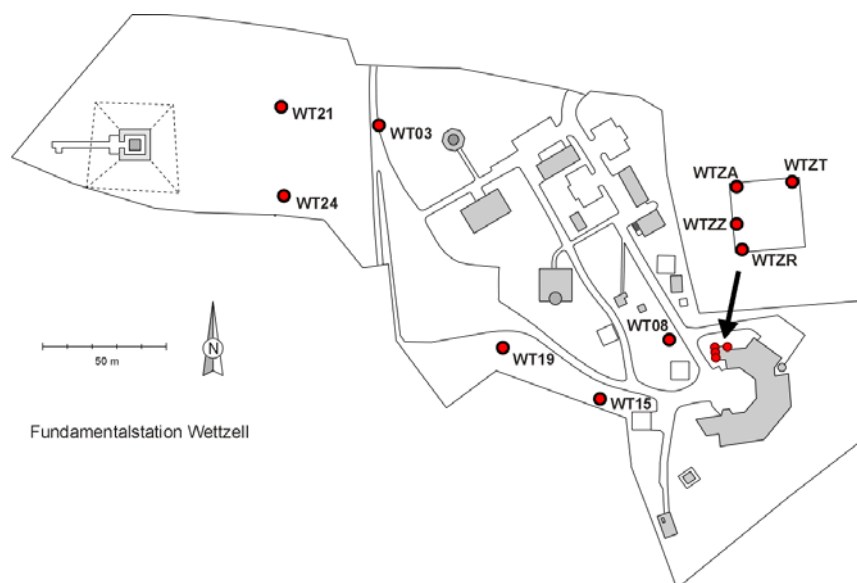


Figure 5: GPS observations during September 27 to October 05, 2003

The second campaign was performed from September 27 to October 5, 2003. The occupied points are shown in the Figure 5. The observations from both periods were combined to one solution employing the Bernese GPS Software, Version 5.0 [6]. The r.m.s values for the coordinates obtained for the daily solutions were better than 1.5mm and for the combined solution between 0,06 and 0,87 mm.

6 Combination of terrestrial survey with GPS results

The solutions of the terrestrial survey results and of the GPS observations were combined employing the Bernese GPS Software under consideration of the variance-covariance matrices in order to obtain the best results for the local ties in the frame of ITRF [7]. Table 3 gives the identical points for the combination.

Table 3: Identical points for the combination

terrestr. survey	GPS
3	WT03
8	WT08
15	WT15
19	WT19
21	WT21
24	WT24
25	WT25
303	W303
304	W304
1201	WTZT
1202	WTZR
1204	WTZA
1205	WTZZ

A Helmert transformation considering 7 parameters (scale, 3 translations and 3 rotations) has been conducted in order to transform the local terrestrial results to the ITRF solution derived by GPS. The residuals in average are for the

X-component : 1.09mm,
Y-component : 1.31mm,
Z-component : 3.04 mm.

The combined results are available in SINEX format (WTZ_SNX1.SNX) at the IERS Central Bureau for further applications.

The local eccentricities in dX, dY and dZ with reference to ITRF are summarized in Table 4. They are referred to the survey monument No. 1.

Table 4: Eccentricities with reference to monument marker No. 1 in dX, dY and dZ

Internal point ID	ΔX	rms ΔX	ΔY	rms ΔY	ΔZ	rms ΔZ
	[m]	[m]	[m]	[m]	[m]	[m]
1	0,00000	0,00151	0,00000	0,00061	0,00000	0,00183
100 (TIGO VLBI)	57,27253	0,00086	20,61512	0,00039	-54,09384	0,00088
200 (TIGO SLR)	80,52671	0,00145	-1,35079	0,00041	-69,82686	0,00154
1201 (WTZT)	63,09859	0,00040	120,97928	0,00039	-67,18717	0,00040
1202 (WTZR)	66,16981	0,00037	119,35753	0,00037	-69,34447	0,00037
1203 (WTZJ)	65,50397	0,00039	120,92659	0,00039	-69,21625	0,00039
1204 (WTZA)	63,97892	0,00039	118,35597	0,00038	-67,45288	0,00039
1205 (WTZZ)	65,04648	0,00039	118,67096	0,00038	-68,43863	0,00039
1206 (WTZL)	63,52703	0,00040	119,66441	0,00038	-67,31879	0,00040
7224=VLBI	25,37253	0,00130	0,96110	0,00052	-8,02375	0,00119
7595	36,70871	0,00059	91,23808	0,00044	-49,53325	0,00094
7596	67,92918	0,00059	103,02342	0,00039	-77,43646	0,00043
7597 (DORIS)	87,38736	0,00103	92,23954	0,00041	-89,59820	0,00098
7598	64,75638	0,00059	72,93692	0,00038	-66,39097	0,00056
8834 (SLR)	62,34602	0,00061	51,15581	0,0004	-53,82678	0,0007

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GPS Monitoring of the Footprint Network of the Fundamental Station Wettzell

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Summary. A footprint network in the vicinity of a fundamental station allows the monitoring of local instabilities. At the Fundamental Station Wettzell four footprint markers are observed continuously with GPS since 2001. The data spanning a period of 2.7 years are analyzed. The horizontal position is monitored with a daily repeatability of better than 1,5mm. The vertical component has a repeatability of 4mm. Such a permanent GPS network is well-suited to monitor the stability.

1 Motivation

Fundamental stations are important reference sites for the global reference frames in particular for the terrestrial reference frame as ITRF. Such a site represents an extended area for plate tectonic motions. Local instabilities or movements have an impact to the results and should be taken into consideration for the interpretation. Local control measurements are of importance to guarantee that no local effects influence the results and lead to wrong conclusions. For the monitoring of local motions, in addition to a local survey network for the determination of local ties, a footprint network has to be setup. Typically a footprint network with an extension of 20-30km should be established. Geodetic measurements have to be carried out periodically e. g. every two or three years with highest geodetic accuracy. Performing the observations is a tremendous amount of work, which requires a lot of manpower. Today permanent installed GPS receiver at footprint markers allow automatic and continuous monitoring of the sites with high accuracy and high resolution in time. Long time series of the station coordinates help to detect periodical signals and significant local movements. Such time series provides accurate information about the local stability in the vicinity of the fundamental station.

2 Footprint network at the Fundamental Station Wettzell

Since January 2001 additional permanent GPS receivers (ASHTech ZXII) were installed at four locations around the Fundamental Station Wettzell which gather continuously 30s GPS data. Figure 1 shows the GPS footprint network. Separated by a distance of 7 km to 19 km from the permanent installed receiver at the station Wettzell (WTZZ), the stations Arber (ARBR), Miltach (MILT), Hohenwarth (HOWA) and Prackenbach (PRAC) operate routinely.

The station heights vary between 488m and 1505m. Figure 2 shows the network geometry with respect to the height differences between the stations.

The data are transmitted to a server and stored for further analysis.

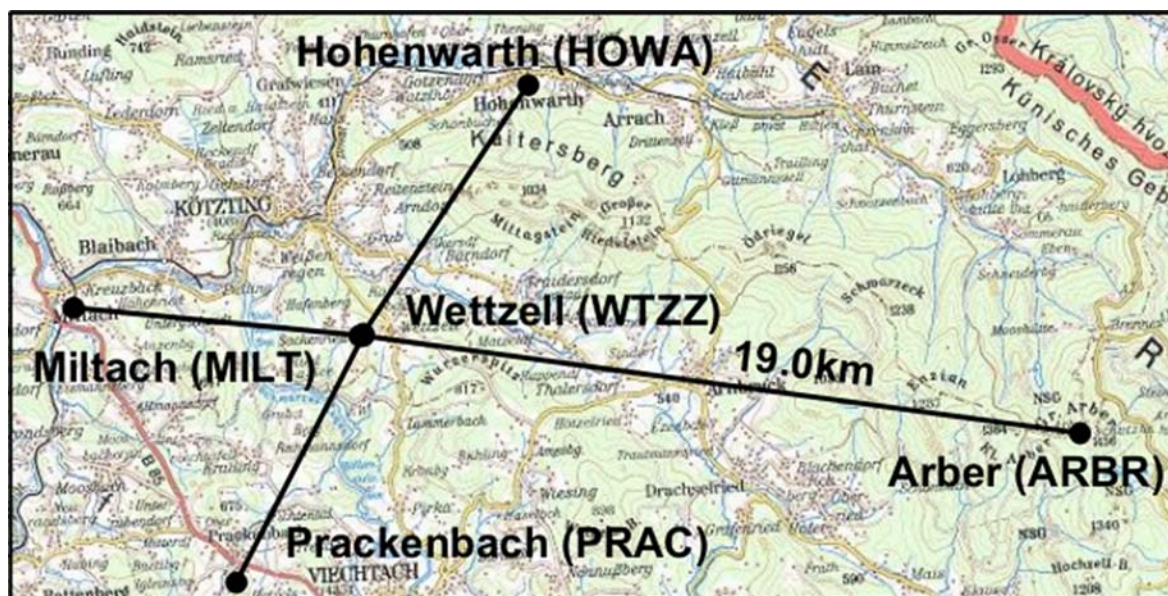


Fig. 1: GPS Footprint Network in the vicinity of the Fundamental Station Wettzell

3 Data Analysis

In the frame of a thesis performed at the Technical University of Munich, the data were analysed and routines for further continuous analysis were set up [1]. The Bernese GPS Software 5.0 was employed, which allows the automatic processing of the data. All data observed in the period from 01.01.2001 to 09.08.2003 (2.7 years) were analysed. Figure 3 shows the analysis strategy for daily solutions.

4 Results

Figure 4, 5 and 6 show the time series of the stations ARBR, HOWA, MILT and PRAC of the north-, east- and height-component with respect to the station WTZZ, which has been kept fixed.

The repeatability of the daily solutions for the stations HOWA, MILT and PRAC is a factor of two better than the repeatability of the station ARBR. The explanation is that the antenna at the station ARBR is housed under a large radome of a radar system, which has been used previously by the military. As the infrastructure at the station ARBR is provided by the military, we accept the higher noise in the data due to our dependence on the support.

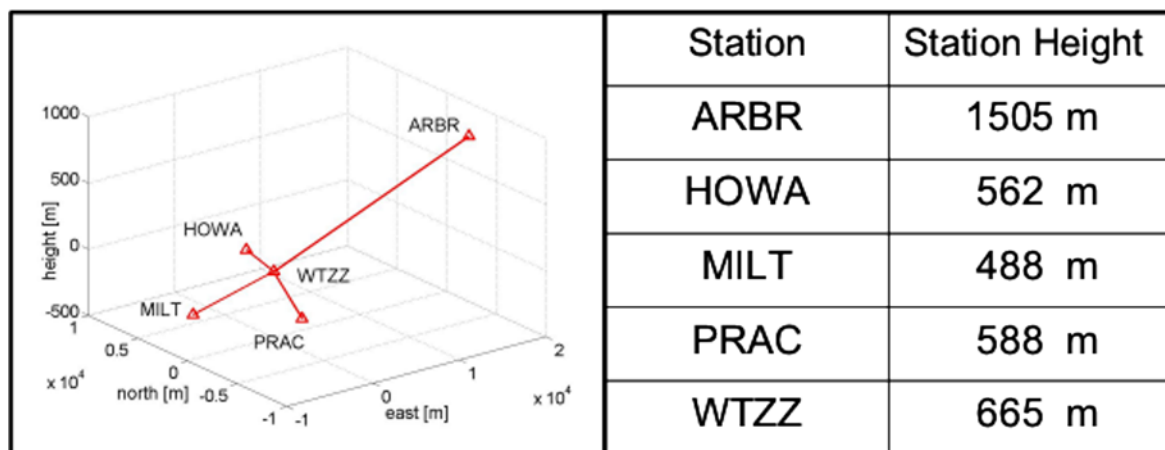


Fig. 2: Height differences between the footprint station

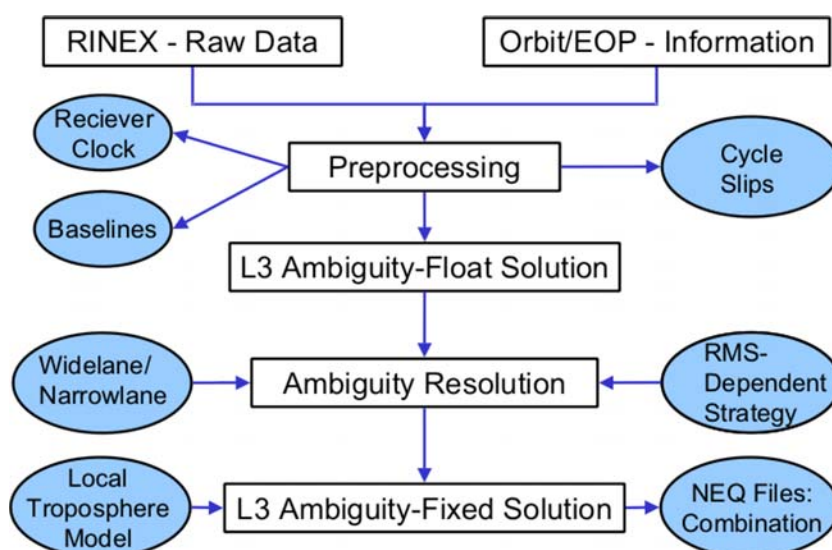


Fig. 3: Analysis Strategy for daily solutions

Figure 5 shows the repeatability of the east components of the stations. A periodic effect occurs for the stations HOWA and MILT with an amplitude of approximately 2mm. The reason is unknown. It might come from seasonal motions of the stations, e.g. due to deformations of the buildings which houses the antennas.

Figure 6 shows the repeatability of the height components. The r.m.s values of the height components are by a factor of approximately 3 worse compared to the north- or east-components.

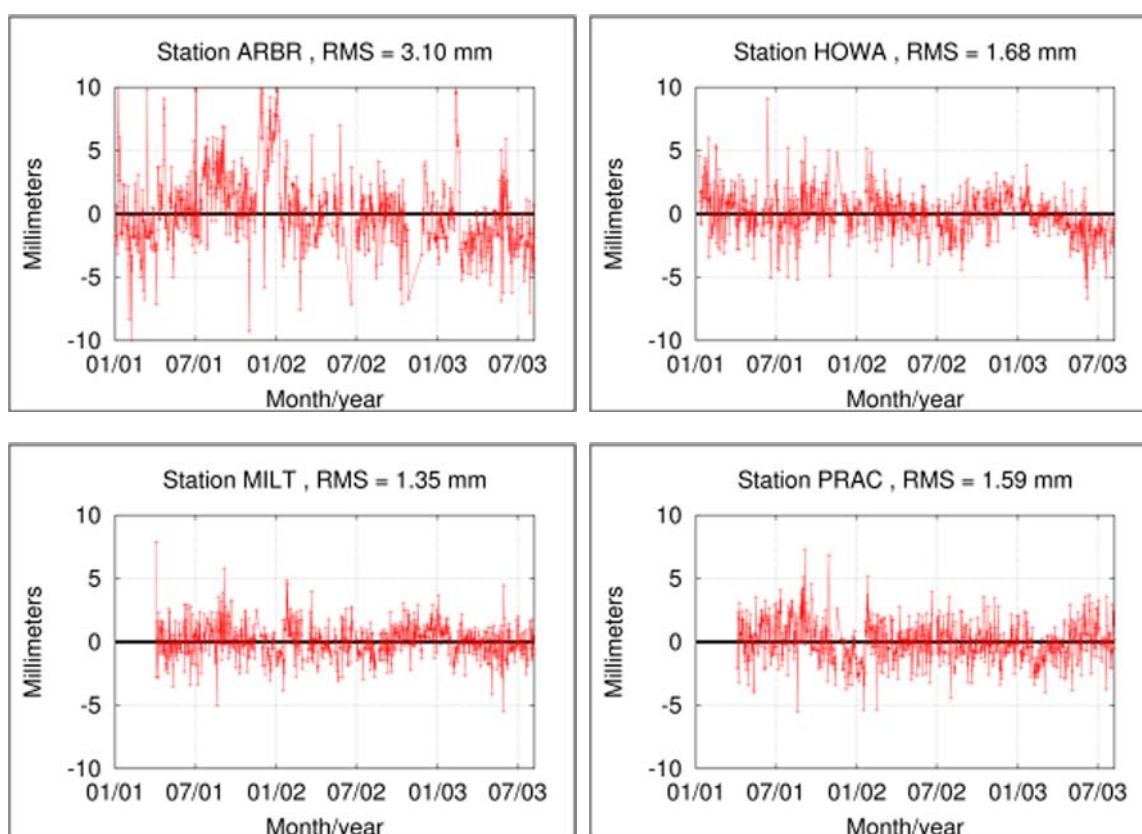


Fig. 4: Repeatability of the north component

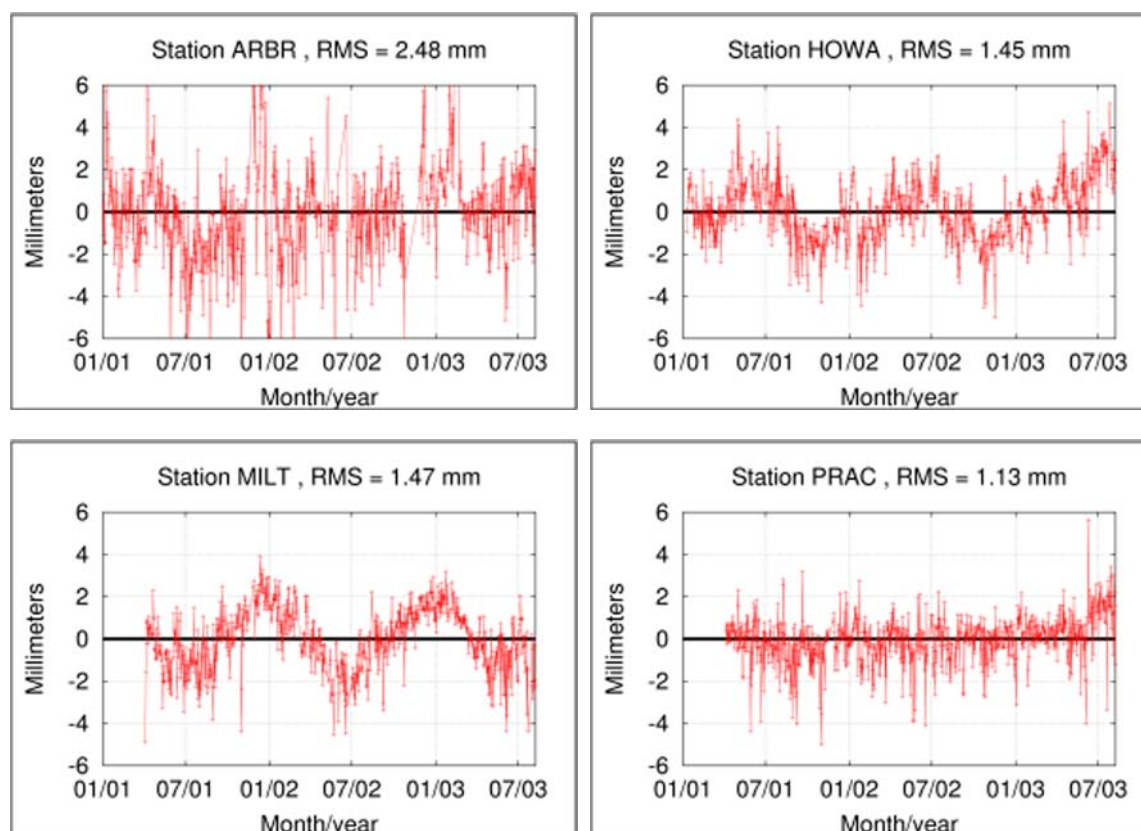


Fig. 5: Repeatability of the east components

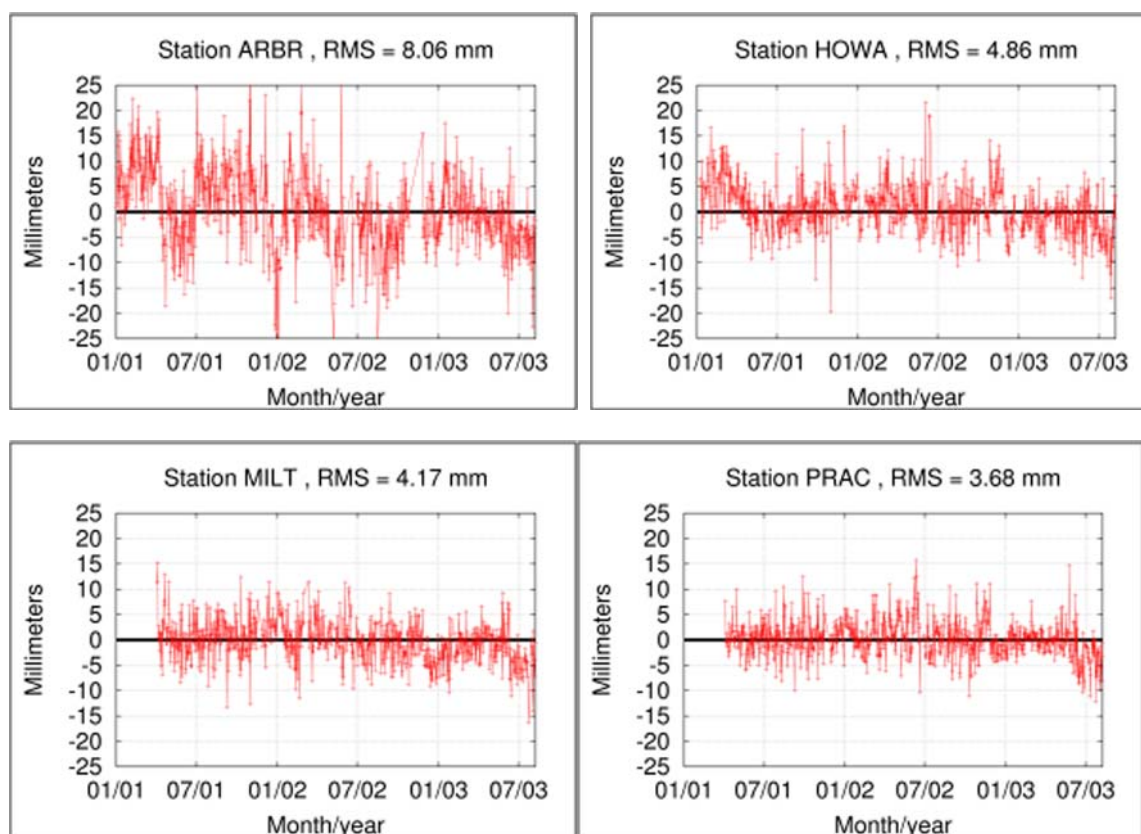


Fig. 6: Repeatability of the height components

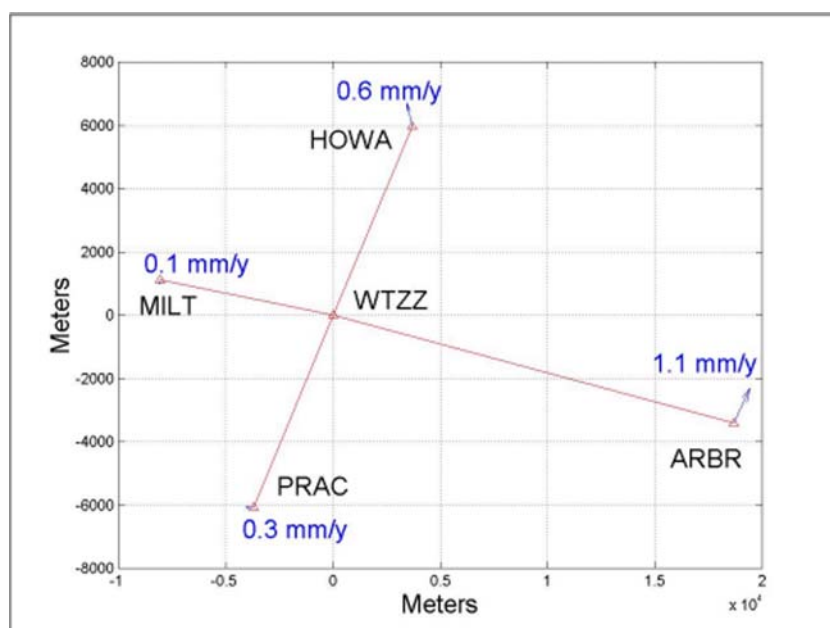


Fig. 7: velocities derived from the time series with respect to WTZZ

Velocities are estimated from the time series of the north- and east-components. The results are summarized in Figure 7. The calculated values are between 0.1mm/y and 1.1mm/y which are not significant.

5 Conclusion

Permanent GPS observations are an excellent tool to monitor the stability of the area around a fundamental station. The daily repeatability of the derived coordinates is approximately 1.5mm in horizontal and 4mm in the vertical position. The time series show systematic behaviour and local motions. The analysis show a seasonal signal for the station HOWA and MILT with an amplitude of 2mm. The reason might be any deformation of the buildings or any modelling problems. No significant movement could be detected during the 2.7 years of observation in the vicinity of Wettzell. The Fundamental Station Wettzell could be regarded as stable.

Reference

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Local Ties Between the Reference Points at the Transportable Integrated Geodetic Observatory (TIGO) in Concepcion/Chile

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Summary. The local ties between reference points of the geodetic space observation systems and the geodetic local network markers have been derived through terrestrial local survey and GPS observations. The local survey consists of direction, distance and levelling observations, which were analysed with the adjustment program PANDA. GPS observations were carried out for the orientation of the local network within the global reference frame. The GPS observations were analysed using the Bernese GPS Software. Both results were combined by making use of the Bernese GPS Software. The results finally were made available in the SINEX format for further application.

1 General Information

Local ties between the reference points of the observing systems co-located with the Transportable Integrated Geodetic Observatory (TIGO) in Concepcion/Chile (figure 1) are fundamental for combining the different space techniques. TIGO, operated by the Bundesamt für Kartographie und Geodäsie in collaboration with the Chilean consortium lead by the Universidad de Concepcion, is equipped with

- a 6m Radiotelescope for VLBI (TIGO-VLBI-Module),
- a Laser Ranging System (TIGO-SLR-Module) for SLR,
- a GPS and GLONASS receiver

In the period from March 10 to April 04 observations have been conducted to derive the local ties with highest accuracy through terrestrial survey. Local GPS observations for the orientation of the local network were carried out in the period from July 29 to July 30, 2004.



Figure 1: Transportable Integrated Geodetic Observatory TIGO in Concepcion/Chile

2 Local Network

The local control network has an extension of 160mx 50m and consists of 14 marked points for the horizontal location and of 31 levelling markers. Four of the points are marked as stable survey pillars (Figure 2), with forced centring capabilities. Additional levelling points are installed for height control. Levelling technique can easily be employed for regular survey in order to monitor local stability. Figure 3 gives an overview of the entire network.

Table 1 gives the point description with the internal station number, the DOMES number and the approximate longitude, latitude and height.

Table 1: Description of local survey points, relevant for combination of space techniques

local marker	DOMES No.	Description	approx. Longitude	approx. Latitude	approx. Height
101	M	ground marker VLBI	286 58 29.7	-36 50 33.9	169.3
102	M	ground marker VLBI	286 58 29.4	-36 50 33.9	169.3
103	M	ground marker VLBI	286 58 29.3	-36 50 33.7	169.3
110	M	marker	286 58 28.3	-36 50 34.0	169.3
111	M	marker	286 58 29.7	-36 50 33.7	169.5
112	M	marker	286 58 29.1	-36 50 34.6	169.3
201	M	ground marker SLR	286 58 28.9	-36 50 34.9	169.3
500	M	PRARE reference point	286 58 27.4	-36 50 37.5	180.8
200 / 7405	41719M001	SLR Intersection of axis	286 58 28.8	-36 50 34.8	170.8
100 / 7640	41719S001	VLBI Intersection of axis	286 58 29.5	-36 50 33.8	171.0
300	41719M002	CONZ; GPS/GLONASS	286 58 28.3	-36 50 37.5	180.7
301	M	pillar monument T301	286 58 29.0	-36 50 35.6	175.3
302	M	pillar monument T302	286 58 28.0	-36 50 34.0	171.0
303	M	pillar monument T303	286 58 30.1	-36 50 33.2	171.0

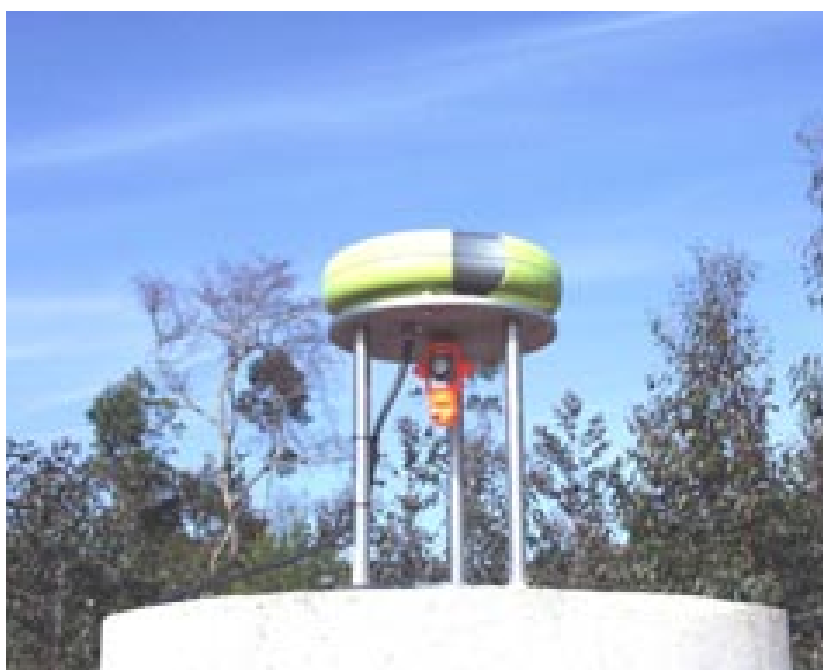


Figure 2: Survey pillar of the local network , Pillar with GPS/GLONASS antenna and reference point realized by the reflector

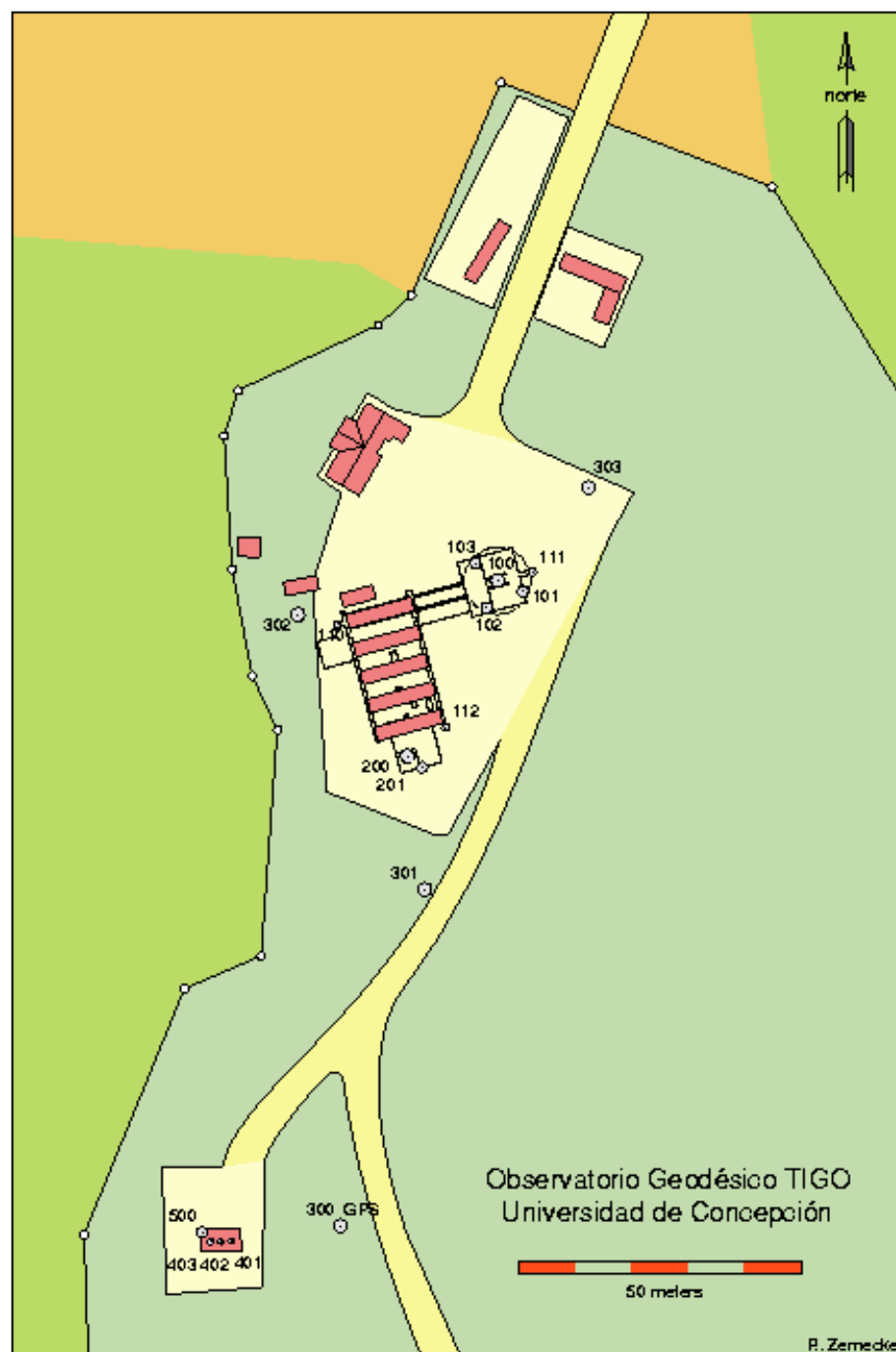


Figure 3: Local Network of TIGO in Concepcion

3 Local terrestrial survey observations

The analysis of the local terrestrial survey is based on observations performed in the period from March 10 to April 04, 2003 by Rudolf Zerneck [1].

For

- distance and direction measurements the Tachymeter “Geodimeter Bergstrand” with a precision of $1\text{mm} + 1\text{ppm}$ for distances and $0,3\text{mgon}$ for directions (Figure 4)
- levelling the Zeiss DINI11 with a precision of $0,3\text{mm/km}$

were employed.



Figure 4: Tachymeter “Geodimeter Bergstrand” used for distance and direction observations

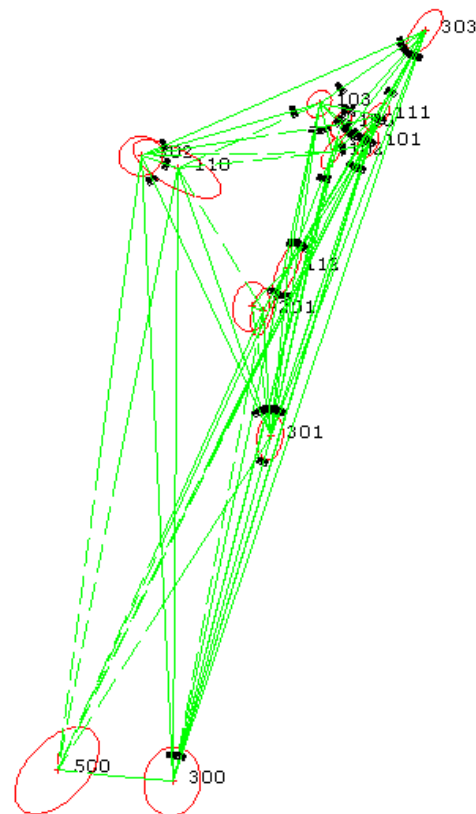
4 3D adjustment of the terrestrial local network

The adjustment of the network has been done with the “PANDA” program [2] by Karin Fischer [3]. The network specific parameters of the adjustment are summarized in Table 2.

Table 2: Network specific parameters of the PANDA free network solution

total number of observations :	467
number of directions :	307
number of distances :	83
number of height differences :	77
total number of network points :	14
number of unknowns :	42
additional parameter estimated :	1
unknown number for orientation :	75
free network parameter:	4
degrees of freedom :	353

The precision obtained for all network points is shown in Figure 5, and demonstrated by the error ellipses for the horizontal location and error bars for height. The goal was to derive local ties better than 1 mm, which is achieved for the entire network. Larger values occur for some border points. All ties being relevant for the combination of the space techniques show small error ellipses with semi axis up to 0.6mm. The point 500 shows the largest errors as it is located at the border and the PRARE mount has not a clear marker for surveying.



Netzmaßstab: $\text{---} = 16 \text{ [m]}$ Ellipsenmaßstab: $\text{---} = 1 \text{ [mm]}$

Figure 5: Accuracy obtained after the adjustment, demonstrated by the error ellipses

5 GPS observations and analysis

GPS observations were carried out in the period from July 29 to July 30, 2004 in order to connect the local network to the global reference frame ITRF. Beside the permanent observing GPS station CONZ three temporary sites were occupied additionally (figure 6).

The observations were analysed employing the Bernese GPS Software, Version 5.0 [4]. The r.m.s values for the coordinates obtained for the daily solutions and the combination were better than 1mm.

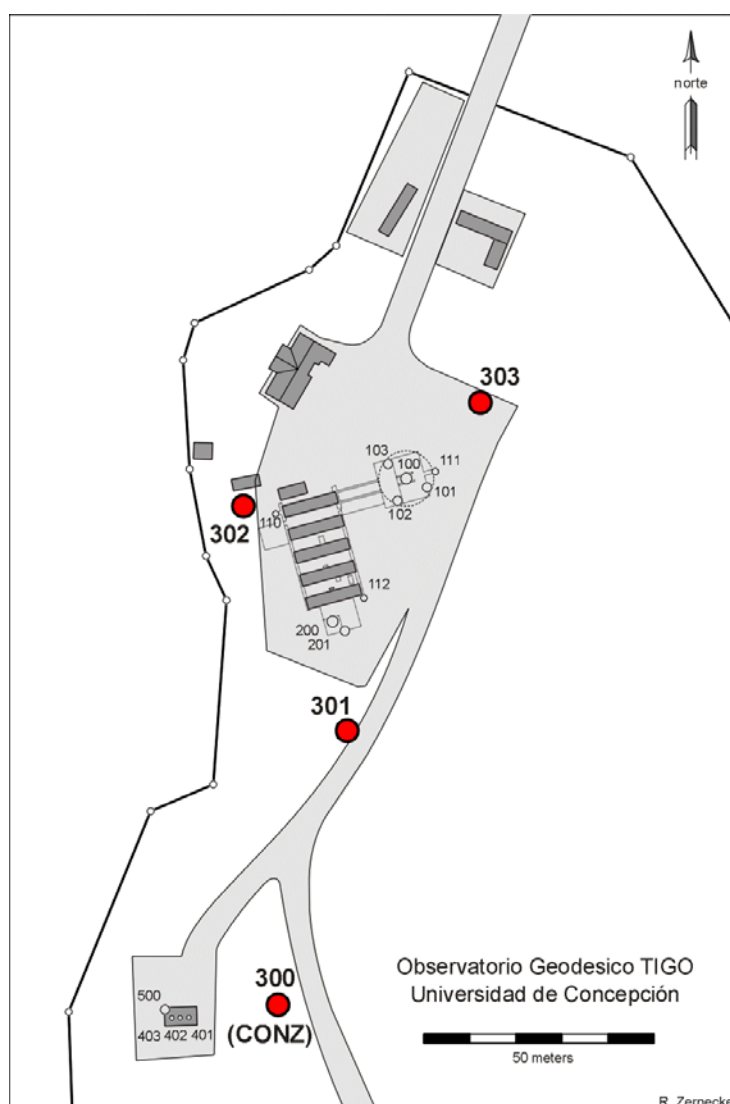


Figure 6: GPS observations during July 29 to July 30, 2004

6 Combination of terrestrial survey with GPS results

The solutions of the terrestrial survey results and of the GPS observations were combined employing the Bernese GPS Software under consideration of the variance-covariance matrices in order to obtain the best results for the local ties in the frame of ITRF [5]. Table 3 gives the identical points for the combination.

Table 3: Identical points for the combination

local survey	GPS
300	CONZ
301	T301
302	T302
303	T303

A Helmert transformation considering 7 parameters (scale, 3 translations and 3 rotations) has been conducted in order to transform the local terrestrial re-

sults to the ITRF solution derived by GPS. The residuals in average are for the

X-component : 0,45mm,
Y-component : 1,54mm,
Z-component : 0.04 mm.

The combined results are available in SINEX format (TIGO_SNX.SNX) at the IERS Central Bureau for further applications. The local eccentricities in dX, dY and dZ with reference to ITRF are summarized in table 4. They are referred to the survey monument Nr. 300 (GPS-reference marker)

Table 4: Eccentricities with reference to monument marker No. 300 in dX, dY and dZ in the frame of ITRF

Local point ID.	Difference of the coordinates with respect to reference marker 300		
	ΔX	ΔY	ΔZ
100/VLBI	46,65616	-50,27257	98,61724
101	50,20110	-45,78870	97,03620
102	43,90655	-46,57316	95,64737
103	43,19069	-52,11146	102,44044
110	17,21135	-52,94528	93,30525
111	52,81520	-48,08339	100,66139
112	32,82776	-37,29325	79,37453
200/SLR	25,75611	-36,36005	73,00866
201	27,18456	-34,12821	73,13721
300/GPS-CONZ	0,00000	0,00000	0,00000
301	26,20255	-25,64263	51,91222
302	11,93011	-57,46872	94,21582
303	63,84058	-55,46231	111,85901
500/PRARE	-19,03940	-7,20666	1,58046

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- [1] Zerneck, Rudolf: Lokale Vermessung von TIGO in Concepcion im Frühjahr 2003, interner Bericht, Januar 2004
- [2] GeoTech GmbH: PANDA für Windows, Laatzen, Version 3.08, Januar 2002
- [3] Fischer, Karin: Auswertung der TIGO-Messungen, September 2003, interner Bericht
- [4] Klügel, Thomas: Auswertung lokaler GPS-Kampagnen in Wettzell und Concepcion, interner Bericht, Januar 2005
- [5] Thaller, Daniela, Peter Steigenberger, Markus Rothacher: Kombination von terrestrischer Messung mit GPS für die lokalen Netze in Wettzell und Concepcion, interner Bericht, Januar 2005

Determination of Local Ties at Ny-Ålesund

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Abstract. The Ny-Ålesund Geodetic Observatory is equipped with two permanent GPS units which are part of the IGS network and the VLBI telescope close by. A DORIS beacon is operated in the vicinity. This paper gives an overview about measurements that have been carried out at Ny-Ålesund in two local survey campaigns in August 2000 and August 2002 and the corresponding results.

1 Introduction

Due to its extreme northern location the co-location site Ny-Ålesund plays an important role in global geodetic and geodynamic studies. In close vicinity to each other a VLBI telescope (Fig. 1) and two GPS units (Fig. 2) are operated routinely in global monitoring programs by the Norwegian Mapping Authority (NMA). A DORIS beacon (Fig. 3) is located on top of the French polar research station in about 1.5 km distance from the VLBI telescope and the GPS units.

The data collected with these space geodetic observing platforms are used for example for Earth rotation investigations (VLBI and GPS) or precise orbit determination (DORIS and GPS). All platforms also provide crucial data for the establishment and maintenance of the International Terrestrial Reference Frame (ITRF) (Altamimi et al. 2001).

Two general requirements have to be fulfilled for successful investigations of the areas mentioned above. For global geodynamic studies the *stability* of the reference points has to be monitored regularly with high accuracy in order to separate local effects from global phenomena like plate tectonics or crustal deformation. At sites with multiple observing platforms the *eccentricities*, i.e.



Figure 1: The Ny-Ålesund VLBI telescope.



Figure 2: The GPS units NYAL (left) and NYA1 (right).



Figure 3: The DORIS beacon.

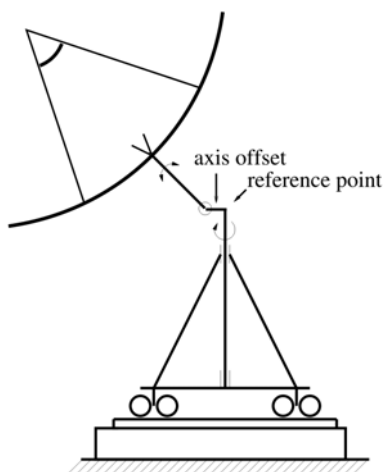


Figure 4: Axis geometry of the Ny-Ålesund VLBI telescope.



Figure 5: Target materialized by a pop rivet at the end point of the elevation axis.

the 3D vectors between the observing instruments, have to be determined and kept up-to-date for the maintenance of the terrestrial reference frame. Both aims can only be reached by repeated precise local surveying. Therefore, two surveying campaigns have been carried out in August 2000 and in August 2002.

The main focus of this paper is on the determination of the local ties between the space geodetic reference points. Results concerning the stability of the reference points can be found in Steinfort et al. (2003) or Kümpel and Fabian (2003). Most methods and observing principles used in the campaigns were already described extensively in recent publications (e.g. Lidberg et al. 2002, Nothnagel et al. 2001, Nothnagel et al. 2002 or Steinfort et al. 2002).

2 Space Geodetic Reference Points at Ny-Ålesund

In geodetic VLBI all parameters estimated in the data adjustment are referred to the so-called VLBI reference point. In the case of an azimuth-elevation mount the reference point is either the point where both axis intersect or, if they do not intersect as in the case of the Ny-Ålesund telescope, it is the point of the azimuth axis where the distance to the elevation axis is minimal (Fig. 4) (e.g. Ma 1978, Nothnagel et al. 1995). This point should be invariant to any antenna movements necessary for the VLBI observations.

The reference point of the Ny-Ålesund telescope is not directly accessible and cannot be materialized, either. In order to determine the reference point, the end points of the elevation axis have been materialized by small pop rivets which were placed in the centric bores of the elevation bearings (Fig. 5). When rotating in azimuth each end point of the elevation axis ideally describes a circle about the VLBI reference point. Determining the 3D positions of the markers at different azimuths subsequently permits the computation of the VLBI reference point as the center of the circles. The average height of the two end points represents the height of the reference point. For full visibility coverage of the targets at the elevation axis end points, three auxiliary survey points on tripods were established augmenting the existing network of concrete surveying pillars (Fig. 6).

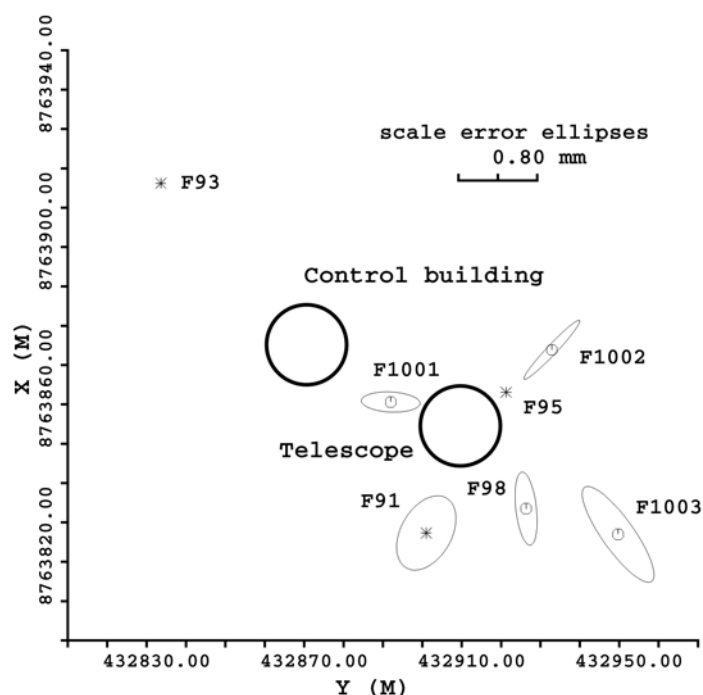


Figure 6: Layout of the Ny-Alesund control network; F91, F93, F95, F98 = pillars; F1001, F1002, F1003 = tripods.

The GPS antenna reference point (ARP) is, in contrast to the somehow virtual reference point of a VLBI antenna, physically defined. Its height is related to the bottom of the pre-amplifier (BPA) of the GPS antenna. The horizontal position of the ARP can be represented by the center of the ground plane. The height components of the ARP and the center of the ground plane differ by 35 mm according to the IGS database (antenna type AOAD/M_T) (Fig. 8).

Since the GPS antenna could not be removed and there was no direct line of sight to the BPA the reference point had to be determined indirectly. In order to determine the reference point four tape markers were used which were affixed to the ground plane at four directions (North, South, East, West, Fig. 7). These tape markers materialize the lower edge of the circular ground plane



Figure 7: NYA1 with tape markers.

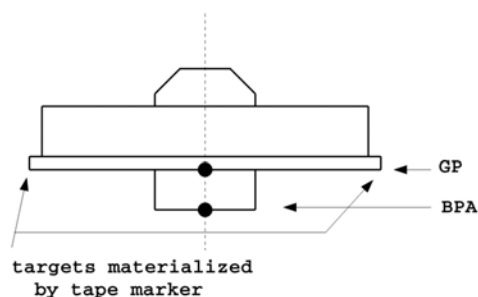


Figure 8: Cross-section of the NYA1 GPS antenna, BPA = bottom of pre-amplifier, GP = ground plane, $\Delta h_{GP-BPA} = 35$ mm.

(Fig. 9). After measuring the 3D positions of the tape markers relative to a control network of tripods through forward intersects it is possible to estimate the position of the ARP as the center of a circle.

The reference point of the DORIS beacon (Starec type) is normally the 400 MHz phase center of the antenna (Fig. 9). If the 400 MHz and 2 GHz phase centers are not on the same vertical line (tilt of antenna) the height reference

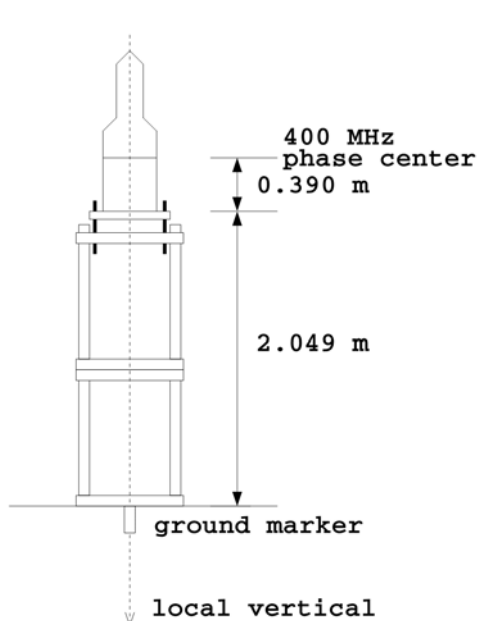


Figure 9: DORIS steel monument with ground marker.

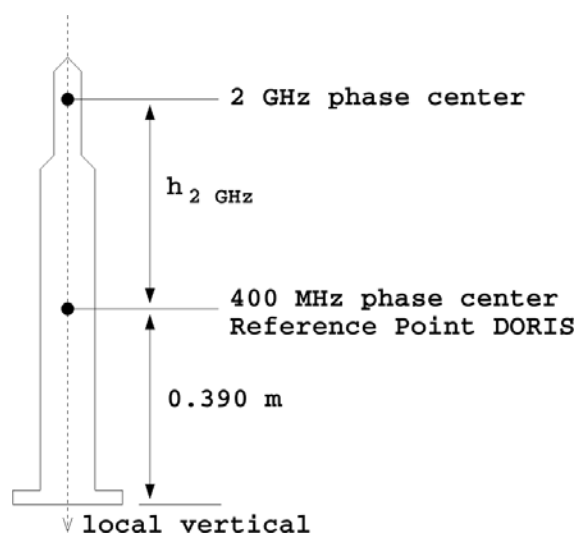


Figure 10: Geometrical characteristics of a DORIS antenna (Starec type); $h_{2\text{ GHz}} = 487\text{ mm}$.



Figure 11: The GPS antenna mounted on the DORIS monument.

of the antenna is the 400 MHz phase center, but the horizontal position is referred to the 2 GHz phase center (H. Fagard, personal communication).

The DORIS beacon is located on a balcony at the building of the French polar research station in Ny-Ålesund village (cf. Fig. 3, Fagard 1999). The local tie between the DORIS antenna and the other techniques was observed by GPS since the distance is too long for a position transfer by terrestrial surveying methods (adverse error propagation).

In a first step, the centering of the DORIS beacon with respect to its nominal position marked by a brass bolt was checked in order to remount the beacon in its proper position (cf. Fig. 9). Then the beacon was dismantled and replaced by a GPS antenna for a 5-day continuous GPS measurement (Fig. 11). At the end of the GPS measurements the DORIS antenna was replaced and the centering was checked again.

3 Forward Intersection vs. Radial Point Determination

This section provides a comparison of two methods for the determination of target points on telescope or antenna structures by classical surveying methods. Figure 12 shows the trigonometric forward intersection, fig. 13 the radial point determination.

The following formulas are used for determining the coordinates of a point P (y_P , x_P) (on a telescope) by forward intersection:

$$\begin{aligned} y_P &= y_A + \overline{AP} \sin t_A^P \\ &= y_A + \frac{\overline{AB} \sin \beta}{\sin(\alpha + \beta)} \sin t_A^P \\ x_P &= x_A + \overline{AP} \cos t_A^P \\ &= x_A + \frac{\overline{AB} \sin \beta}{\sin(\alpha + \beta)} \cos t_A^P \end{aligned}$$

and by radial point determination:

$$\begin{aligned} y_P &= y_A + \overline{AP} \sin t_A^P \\ x_P &= x_A + \overline{AP} \cos t_A^P \end{aligned}$$

using the parameters of figures 12 and 13. The error propagation uses the partial derivatives of the coordinate components w.r.t. to the observations and parameters introduced from the ground network. Assuming that the uncertainties of the coordinates of A (y_A , x_A) are not of interest here the error propagation law for forward intersection is

$$\begin{aligned} \sigma_{y_P}^2 &= \left(\frac{\partial y_P}{\partial t_A^P} \right)^2 \sigma_t^2 + \left(\frac{\partial y_P}{\partial \alpha} \right)^2 \sigma_\alpha^2 + \left(\frac{\partial y_P}{\partial \beta} \right)^2 \sigma_\beta^2 + \left(\frac{\partial y_P}{\partial \overline{AB}} \right)^2 \sigma_{\overline{AB}}^2 \\ \sigma_{x_P}^2 &= \left(\frac{\partial x_P}{\partial t_A^P} \right)^2 \sigma_t^2 + \left(\frac{\partial x_P}{\partial \alpha} \right)^2 \sigma_\alpha^2 + \left(\frac{\partial x_P}{\partial \beta} \right)^2 \sigma_\beta^2 + \left(\frac{\partial x_P}{\partial \overline{AB}} \right)^2 \sigma_{\overline{AB}}^2 \end{aligned}$$

with

$$\begin{aligned}
 \frac{\partial y_P}{\partial t_A^P} &= \overline{AP} \sin t_A^P \\
 \frac{\partial y_P}{\partial \alpha} &= -\overline{AP} \cot(\alpha + \beta) \sin t_A^P \\
 \frac{\partial y_P}{\partial \beta} &= \frac{\overline{BP}}{\sin(\alpha + \beta)} \sin t_A^P \\
 \frac{\partial y_P}{\partial AB} &= \frac{\sin \beta}{\sin(\alpha + \beta)} \sin t_A^P \\
 \frac{\partial x_P}{\partial t_A^P} &= \overline{AP} \cos t_A^P \\
 \frac{\partial x_P}{\partial \alpha} &= -\overline{AP} \cot(\alpha + \beta) \cos t_A^P \\
 \frac{\partial x_P}{\partial \beta} &= \frac{\overline{BP}}{\sin(\alpha + \beta)} \cos t_A^P \\
 \frac{\partial x_P}{\partial AB} &= \frac{\sin \beta}{\sin(\alpha + \beta)} \cos t_A^P
 \end{aligned}$$

and for radial point determination

$$\begin{aligned}
 \sigma_{y_P}^2 &= \left(\frac{\partial y_P}{\partial t_A^P} \right)^2 \sigma_t^2 + \left(\frac{\partial y_P}{\partial AP} \right)^2 \sigma_{AP}^2 \\
 \sigma_{x_P}^2 &= \left(\frac{\partial x_P}{\partial t_A^P} \right)^2 \sigma_t^2 + \left(\frac{\partial x_P}{\partial AP} \right)^2 \sigma_{AP}^2
 \end{aligned}$$

with

$$\begin{aligned}
 \frac{\partial y_P}{\partial t_A^P} &= \overline{AP} \cos t_A^P \\
 \frac{\partial y_P}{\partial AP} &= \sin t_A^P \\
 \frac{\partial x_P}{\partial t_A^P} &= -\overline{AP} \sin t_A^P \\
 \frac{\partial x_P}{\partial AP} &= \cos t_A^P
 \end{aligned}$$

The comparison of the formulas shows that both types of coordinate determinations, forward intersection and radial point determination, as well as their error propagation contain contributions of the distance to the target point $P(\overline{AP})$ or of the baseline between the control network points A and $B(\overline{AB})$. In the case of the radial point determination each distance $(\overline{AP})$ for

a number of target points depends on the accuracy of the electronic distance measuring instrument and, in addition, has to be measured for every point anew. Both facts may contribute some additional uncertainty, either by a scale factor or an additive error. For the forward intersection method the baseline $\overline{AB}$ is normally determined within a complete network of ground points. Therefore, the scale of the network is robustly determined on the basis of redundant distance measurements which control each other and avoid additive errors. Thus, using the forward intersection method applied from a network of ground stations contributes to the stability of the coordinate determination of (telescope) points.

4 Results

The analysis of the trigonometric measurements was carried out with the least squares adjustment program Panda (GeoTec 1998). After some testing the topocentric coordinates of point F93, the East and North component of F95 and the Up component of F91 were fixed in the least squares adjustment to the coordinates used in the 2000 campaign (e.g. Nothnagel et al. 2002). The topocentric coordinates for the VLBI and the GPS reference point were then estimated in this local frame (Tab. 1).

Table 1: Topocentric coordinates of the VLBI and GPS reference points

	East [m]	σ [mm]	North [m]	σ [mm]	Up [m]	σ [mm]
VLBI	432927.7704	0.8	8763860.7518	0.1	87.2926	0.2
GPS	432836.5156	0.1	8763915.2683	0.1	84.1872	0.5

Table 2: Geocentric Coordinates of the VLBI and GPS reference points after transformation

	X [m]	σ [mm]	Y [m]	σ [mm]	Z [m]	σ [mm]
VLBI	1202462.7055	0.7	252734.4291	0.8	6237766.0458	0.3
GPS	1202433.9070	0.2	252632.2608	0.1	6237772.5076	0.5

Eccentricity vectors between different observing techniques to be used in the computations of the ITRF are normally given in geocentric X,Y,Z coordinate differences. Since the coordinates of the surveying pillars have been computed in both systems, i.e. in global X,Y,Z and in topocentric North,East,Up coordinates, it is possible to transform one system into another by a simple 7-parameter Helmert transformation (Tab. 1 and 2).

Table 3: Geocentric Coordinate Differences relative to NYA1 (VLBI - NYA1 and DORIS - NYA1 resp.)

to point	Year	dX [m]	σ [mm]	dY [m]	σ [mm]	dZ [m]	σ [mm]	Distance [m]	σ [mm]
VLBI	2002	28.798	1.0	102.168	1.0	-6.462	1.0	106.344	1.0
	2000	28.794	2.0	102.162	2.0	-6.470	2.0	106.339	2.0
	mean	28.797	1.0	102.167	1.0	-6.464	1.0		
DORIS	2002	360.061	1.7	1530.850	1.5	-162.944	5.7	1581.043	

Table 3 summarizes the geocentric eccentricity vectors between the NYA1 GPS reference point and the VLBI and DORIS reference points. The standard deviations of the values derived in the 2000 campaign are mainly influenced by the determination of the NYA1 reference point. This was measured by GPS only in the precise point positioning mode (NMA, personal communication). In order to calculate a reasonable weighted mean and to mitigate a disproportion of the two campaigns the standard deviations of the 2002 eccentricities were fixed to 1.0 mm giving the NYA1 reference point measured by terrestrial methods a stronger weight. In addition, the standard deviations of the mean values (cf. Tab. 3) were also fixed to 1.0 mm which corresponds approximately to the accuracy of the terrestrial measurements. The resulting mean values are intended as updates to the previous figures originating from the 2000 campaign and will be published in the SINEX format.

It should be mentioned here that the vectors as computed from the ITRF2000 coordinates of these reference points (VLBI-NYA1 $\Delta X = 28.794$ m, $\Delta Y = 102.166$ m, $\Delta Z = -6.475$ m; DORIS-NYA1 $\Delta X = 360.060$ m, $\Delta Y = 1530.851$ m, $\Delta Z = -162.949$ m, Distance = 1581.044 m) show a good agreement with the vectors determined in this study.

The survey setup chosen here also offers a good opportunity to check the antenna axis offset. The results of the two campaigns agree quite well (difference 0.6 mm, Tab. 4) again confirming the significant discrepancy of the value provided by the manufacturer from the value determined on site.

Table 4: Axis offset

Year	Offset [m]	σ [mm]
manufacturer	0.5080	
2000	0.5245	0.3
2002	0.5239	0.3
mean	0.5242	0.2

One of the reasons for such a big discrepancy may be the fact that the VLBI reference point cannot be materialized and that the manufacturer determined this value just by trying to measure it with the help of a CAD software. In addition, the actual telescope construction at Ny-Ålesund is not necessarily the same as it was projected (H. Digre, personal communication).

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Activities of the IGN Special Works Department

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During 2003 the IGN Special Works Department undertook a number of studies on co-location sites in the field. It has become clear that an overview of the work carried out by this Department would be useful to provide a better understanding of the scope of activities provided by this Department.

The Department:

- 13 permanent staff: 2 engineers, 8 surveyors, 3 assistant surveyors
- Up-to-date equipment: Leica SR530 GPS receivers, Leica TDA5005 and TCA2003 total stations, etc with a range of accessories
- Support from personnel in the Geodetic and Levelling Service (about 70 persons) for major ad hoc missions.

The Department was created at the start of the 1960s, at a time when major infrastructure works were being undertaken, for example by the RATP (extension of metro lines) and the AEC (start of construction of nuclear power stations).

The geodetic surveyors very quickly adapted large scale triangulation methods and implemented them at these smaller sites that required a higher level of precision.

This ability to adapt standard methods and carry out special developments enabled these techniques to be used for various types of site:

- - monitoring civil engineering constructions
- - high precision measurement in laboratories or particular sites
- - monitoring unstable areas

in fact, all types of work requiring precision and uniformity.

This adaptability has played a significant role in the development of the Department, and is perhaps even more important now, at a time when many different technical fields are converging: the world of topography is now merging with the world of graphics.

The following projects illustrate the current range of methods that have been implemented as well as presenting the potential for future projects.

This document outlines projects carried out by the Department (including monitoring movement, laboratory work and sundry measurements).

Note: the term "geodetic metrology" describes the use of geodetic techniques to measure objects with clearly defined shapes (ranging from a few metres to a few kilometres) while providing a precision characteristic of metrology (from a tenth of a millimetre to a few centimetres, depending on the size of the object).

1 Geodetic metrology

1.1 Monitoring movement

The term “monitoring movement” covers several types of work:

- Monitoring civil engineering constructions
- Ground movement
- Safety monitoring

A representative example of each of these categories is described below.

1.1.1 Monitoring civil engineering construction

Objects, such as a bridge, are expected to change with time and thus their shape will alter. Measurements are taken to quantify these changes and ensure that the movement, displacement or deformation measured are in accordance with the behaviour models associated with the object being monitored. Measurement campaigns are usually undertaken at regular intervals (every 6 months, every year, or every 5 years).

There are two main measurement methods:

- - static measurements made using standard surveying methods
- - dynamic measurements using systems that take measurements over a given period of time, typically 24 hours.

In the following example both methods are used.

Study at Charléty Stadium

Sébastien Charléty stadium in Paris is used for many sports events and is, therefore, monitored very closely. Apart from regular visual inspections and measurements provided by individual sensors, an annual inspection is carried out by surveying the building.

The first phase of this inspection is to use various traverses for levelling. These measurements provide information about the behaviour of the lower part of the building (close to the plinth and foundations) to detect any subsidence in the structure.



Figure 1: Sébastien Charléty stadium in Paris

These measurements are made relative to control stations outside the building. Once the control stations have been checked for movement, the absolute movement of the stadium, including overall subsidence, can be measured.

The second stage of this inspection involves standard coordinates measurements:

- - several control stations at intervals around the field are used to determine the coordinates of prisms attached to the upper part of the structure, in particular on the roof framework.
- - the measurements are made with reference to control stations, the height of which has been determined by levelling.

The third part of the inspection uses a motorised surveying system in the centre of the field to track a certain number of the prisms used in the previous phase as well as points on the aerial parts of the construction (lighting masts, roof limits). This system is set up for a period of 24 hours and is used to quantify the movement of selected points (the movement of the lighting masts, for example, is directly linked to their orientation with respect to the sun). A meteorological station is also set up for the period during which the measurements are being taken.

The first two phases are carried out using the principle of a sufficient redundancy of measurements to provide high quality results using least squares. The last phase, however, as implemented on this site does not provide sufficient redundancy, mainly for cost reasons. However, it would be possible to use a second system to duplicate the measurements and thus have sufficient redundancy.

All these measurements are used to provide the sets of coordinates for each of the measurement campaigns and graphs showing the movement measured. We do not analyse this information: this is the task of building construction experts.

1.1.2 Ground movement

A significant part of the Department's work involves checking the stability of natural areas. Some industries, such as salt mines, for example, extract significant quantities of material from the ground. This may cause surface movement, which must be surveyed.

The aim of the survey is, therefore, similar to that for civil engineering works. However, in this case usually only the heights need to be compared on successive dates.

Study at Poligny (Jura)

This site has been mined for many years. Current regulations require the operator to provide the authorities with certain information in order to be able to continue mining.

This submission requires levelling measurements to be carried out. The measurements are made using a standard procedure.

- closed loop measurements or back and forth measurements, depending on the degree of precision and reliability required
- association of all the measurements with one or more control stations, which are themselves checked during the study.

The results are calculated using least squares to provide an indication of the precision actually obtained during the measurements. The site management is then responsible for explaining to the authorities the reasons for any movement that may have been detected.



Figure 2: Poligny (Jura), this site has been mined for many years.

1.1.3 Safety monitoring

Monitoring civil engineering constructions and ground movement could be considered to be safety monitoring. The distinction that is drawn here is related to the general context for setting up monitoring as well as the period over which measurements are taken. We define safety monitoring as:

- - implementing automated techniques
- - continuous or long-term measurement
- - automated processing, often setting up alarm systems

All the techniques used - theodolites, total stations or GPS receivers - can be automated. After a teaching period, each of these methods (associated with a



Figure 3: Safety monitoring in Amsterdam

computer) can operate autonomously and send information to a central processing unit.

The teaching period consists of defining the points that must be observed and the intervals at which measurements are taken (continuously, once an hour, etc).

The information may be sent by cable, radio, etc, and the measurement can also be processed using a least squares method configured to suit the type of equipment used. Finally, depending on the type of site, alarm systems are often set up to warn of any movement detected. The following example is typical of this type of monitoring and is of special interest as it is currently the largest project of its type.

Safety monitoring in Amsterdam

As part of the construction of a new metro line, Amsterdam wished to set up a very comprehensive system for monitoring buildings liable to be affected by the digging of the tunnel.

Apart from a network of individual sensors and a standard levelling campaign, a system using 74 automatic tacheometers was set up.

This system has been in operation 24 hours a day since the start of 2000 and is intended to remain in operation until the end of the project, which is currently scheduled for completion in 2008.

The system was installed in three steps:

- about 5500 prisms were set up
- 74 tacheometers were set up
- the tacheometers were configured

After setting up the radio transmission equipment, the tacheometers were grouped into networks depending on the geometric shape of the observation areas. The results from each group are automatically calculated using least squares.

This system has already shown that its sizing meets the initial requirements of the customer to detect vertical movements of more than 0.9 mm and horizontal movements of more than 4 mm.

The examples described above represent the main work of the Department.

The following paragraphs describe the diversity of the subjects covered, using surveying techniques and related to the profession of surveying.

1.2 Laboratories, industrial trials

This aspect of the activities of the Department only represents a small part of the work load. However, projects undertaken in laboratories usually require a very high level of precision and some of these methods can sometimes be used for larger sites.

This type of work generally involves:

- angle measurements
- inclination measurements

as well as high precision GPS measurements and, occasionally, gravitational measurements.

IGN has a GAK1 gyro attachment for measuring angles. This can be used for relatively accurate measurements (the typical precision of this type of work is

better than 10 seconds) that are usually sufficient to meet the requirements defined by the customer.

Inclination measurements use various types of inclinometer with varying degrees of precision, again designed to meet the customer's requirements.

1.3 Sundry measurements and positions

In addition to these special types of measurement, work is also carried out using GPS.

This is an important part of the Department's activities. It covers all the projects that use GPS in various ways mainly depending on the calculation methods used.

The first category of work consists in determining points, that may be individual or in a network, using static measurements, the aim being to provide the most precise coordinates possible for a given system. This type of activity provides customers with one or more perfectly defined control stations (including the associated precision) for future measurements that will use these control stations.

Another activity related to the GPS consists of ground tractography. Vehicles were equipped with GPS systems for tractography to meet the rather unusual requirements related to the end of mining operations. The aim was to provide an economic solution to quantify the potential subsidence in certain areas by going along roads and tracks at regular intervals and comparing the trajectories to infer the extent of the movement with time.

Another experiment using tractography was carried out in West Africa (between Tangiers and Abidjan) to provide NASA with data for assessing the SRTM Space Shuttle mission.

Finally, GPS techniques are also used to set up procedures for monitoring moving objects in real time.

The first major application was on the Verrières Viaduct (north of Millau Viaduct) where the deck laying was monitored using both standard surveying techniques and standard real time GPS.

The results of this test were conclusive but nevertheless revealed certain limitations of conventional real time procedures. After this test, a monitoring programme on behalf of the Millau Viaduct Construction Inspection Agency (representing the French government) was set up. This was based on a process of transmitting measurements in real time and using a more powerful calculation program, making it possible to use measurements taken by several fixed measurement units. The results obtained therefore had a precision indicator that was more reliable than for more standard processes.

2 Expertise, consultancy

All the activities presented up to now have been projects carried out by Department personnel from the design phase through to the final report stage. Sometimes the Department does not follow a complete project through as in the case of requests for assessment or consultancy.

- Consultancy. The Department carries out simulations to predict the expected results using a virtual implementation based on information provided by the customer.
- Assessment. The Department carries out a verification using its expertise to identify significant elements in a service carried out by a third party.



Figure 4: Verrières Viaduct (north of Millau Viaduct)

A typical example of simulation is the Amsterdam study. Before even knowing which company would be responsible for setting up the safety monitoring system, the whole site was the subject of several simulations enabling us to establish the precision that we considered realistic. Various geometric configurations associated with various types of equipment were tested to provide the most objective assessment of the number of measurement devices that would be required.

Assessments may take various forms, such as

- - angular measurements during tunnelling or checking existing networks
- - criteria for evaluating innovative methods for surveying
- - requests for assessing results as representatives of the courts

As this work is confidential it will not be described in further detail.

3 Research and development

The Department also undertakes various development projects.

Like surveying projects, development projects can also be divided into an acquisition phase, a processing phase and a report phase.

We are working on improving the use of the measuring equipment and on incorporating laser scanning techniques into our work. We are also considering the use of photogrammetry. Assembling images, laser scans and the localisation of these looks to offer promising prospects for some of our fields of activity.

A project investigating the accuracy of deformation tensors is under way with the aim of providing results that are more meaningful for the analysts who use them.

Finally, there is a project investigating the publication of results in the form of a dynamic representation using a 3D GIS incorporating all the information obtained for each measurement campaign relating to a given site.

Hartebeesthoek Co-location Survey

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1 Introduction

The ITRF is the result of a combination of the different terrestrial reference frames provided by the four space geodetic techniques GPS, VLBI, SLR and DORIS. To perform this combination between independent reference frames, it is necessary to get some co-location sites where the various techniques are observing and whose ties have been surveyed in three dimensions. Many co-location sites have been identified and some of them have missing or inconsistent ties.

In this frame, it has been decided as one of the top priorities to survey Hartebeesthoek co-location site (South Africa). Indeed, this site is one of only two sites where the four techniques are currently observing. Some of ties at Hartebeesthoek were missing, and some others were inconsistent.

This paper briefly presents the local ties survey of Hartebeesthoek site that took place during the summer 2003, from the observations on site to the computation of the SINEX file. All the presented results can not be considered as the final ones, since further improvement has to be developed.

2 Survey description

2.1 Organization

The local ties survey of Hartebeesthoek co-location site is a cooperative project in which the four following agencies participated: Hartebeesthoek Radio Astronomy Observatory (HartRAO), NASA Goddard Space Flight Center (GSFC), Institut Géographique National (IGN) and the South African Department of Land Affairs. The survey team gathered 5 members ; Jim Long coming from NASA GSFC who has experience in numerous local ties surveys ; Valérie Michel, Céline Corbière, and Georgia Roesch from the Special Works unit of IGN, which mainly deals with micro-geodesy and metrology ; and Sean Dane from Surveys and Mapping service of the South African Department of Land Affairs. Also, this project took many benefits of support from the HartRAO personnel and facilities, such as the machine shop.

The survey took place from July, the 22nd to August, the 12th 2003. The meteorological conditions have been very appropriate for such a fieldwork since it was sunny almost everyday and all the outside work was easy to plan, even if in a topometric sense the bright sun is not always an advantage during the measurements. Furthermore, in planning the survey work, it was necessary to coordinate with the astronomic observations planning for the VLBI and SLR.

2.2 Site

The Hartebeesthoek co-location site is located in the Gauteng province, in a valley in the Magaliesberg hills, 50 km west of Johannesburg, South Africa. Hartebeesthoek co-location site can be divided into two sub-sites. These sites are each cover an area around 300 meters, on a side and about 3km apart.

For each subsite, a local control network was set up, from which the instruments were observed and tied together with GPS observations.

The first subsite is on HartRAO site. On this site, one can find a 26-meters VLBI radio telescope, a 30-inch diameter SLR telescope (MOBLAS-6) and the IGS GPS station (HRAO). The site is organized such that 7 reinforced concrete piers surround the space geodetic instruments. These piers are 1.2m to 3m high and their diameter is 0.5m. They are all equipped with self-centring devices and are mostly used for SLR calibration targets what gives an explanation about the tall height of the piers.

The second subsite is on the Satellite Application Centre (SAC) site. A DORIS antenna is implanted, very close to another IGS GPS permanent station (HARB). Three pillars equipped with self-centring devices have been set up around this site.

2.3 Equipment

All the topometric survey instruments and equipments belong to IGN or NASA and had been temporarily imported for the needs of the survey.

2.3.1 Instruments

Leica total stations (TC2002 and TDA5005) were used. Those total stations, which are regularly calibrated at IGN's calibration unit, have a standard deviation of 0.15mgon about angles and 1mm+1ppm about distances. Two Leica accurate corner cube reflectors (GPHP1P), which are calibrated with the total stations were used to determine distances.

For the altimetric observations, an electronic level (Leica NA3003) and invar bar code staffs were used. This equipment, regularly calibrated at IGN's calibration unit, has a resolution of 0.01mm.

For the GPS observations, four Leica SR530 receivers with Leica AT504 choke ring antennas were used.

All these instruments allowed the observations be recorded electronically on PCMCIA cards or REC modules and are then downloaded to laptop PC for processing.

2.3.2 Equipment and accessories

Several very useful accessories have been also brought for this type of field-works. These accessories included such items: as heavy tripods, in order to ensure the stability of temporary stations; a translation stage in order to centre a target on a rotation axis; 0.5m, 1.8m and 3.0m long Invar staffs that are all calibrated and associated to each other; calibrated trefoils targets, prisms and tacheometers; trivet plates and tribachs regularly calibrated.

2.4 Observations

2.4.1 Terrestrial observations principles

All the visible lines of sights have been observed with the tacheometers described in 1.3.1.

Horizontal directions and zenith distances were observed in sets, with each set consisting of one reading in both direct and reverse telescope positions. Any observed angle was rejected if the difference between the two circles was greater than 1mgon. Distance measurements were observed over each line one time in both direct and reverse positions. Meteorological data (atmospheric pressure and temperature) were recorded at the beginning of each station.

All the piers are concrete piers with forced-centring devices imbedded in the top. During the observations, Wild or IGN trivet plates were used, which ensured that the targets and total stations were always on the same planimetric position. On each pier, two different total stations have been set up and two different operators observed, in order to avoid any systematic effect. The heights above the reference point of each monument were measured after each set up on three different points with a calliper rule.

As far as direct levelling is concerned, a forward run and a backward run were observed between each benchmark. Before each workday, the instrument collimation was checked. The electronic level instrument was set to perform two readings on bar code staff, and that measurement was rejected if the difference between the two readings was greater than 0.04mm . In the same way, if the difference between the two runs was greater than $0.1\text{mm}/\sqrt{n}$, with n is number of traverse legs, a third run was completed.

Some of the piers of the ground control networks were too high to be levelled by direct levelling. Therefore, indirect levelling was done between the benchmark installed on the pier and a target on the top of the pier.

2.4.2 HartRAO polygon

This control network polygon includes 6 concrete piers, the SLR telescope (a total station has been set up on the top of the telescope right on the vertical axis), the IGS GPS antenna (which has been intersected). The VLBI can also be included in this polygon, since a particular moving point has been observed using the 6 piers.

a. S.L.R.

DOMES NUMBER : 30302M003



Global view of the telescope

The SLR measurements refer to a point in the telescope optics where the two rotation axes intersect.

In a first time, the SLR vertical axis rotation was determined. From one total station set up on a heavy tripod, a target on the translation stage was sighted and the direction recorded. The SLR has been rotated 180° around the vertical axis, and the same target sighted again. Then the translation stage was adjusted of half the difference of the two directions. The same thing was done with the SLR telescope oriented at 90° from the original position. This operation was repeated until the target doesn't move, when sighted with the total station, regardless the direction the SLR is pointing.

In a second time, this rotation axis, determined as described above, was marked on the brass disk of the ground mark. Two different methods were used and they agreed to less than 1mm :



Target and translation stage on top of the telescope



Eccentricity measurement above the brass ground mark (IGN method)

- NASA-GSFC method : using 3 total stations in 3 different directions, the operator sighted the target on the top of the SLR, and went vertically down to the ground mark. The point was then determined using graphical method.
- IGN method : using 3 total stations in 3 different directions, the operator sighted the target on the top of the SLR, and went vertically down to a target on a translation stage above the brass part. By iteration, the target was brought to the SLR axis. A needle took the place of the target on the translation stage and stuck the brass disk.

The horizontal axis was not determined during this survey. The previously determined value of 0.489m was used for the offset from the top of the SLR telescope to the horizontal axis of rotation.

b. IGS station HRAO

DOMES NUMBER : 30302M004



ChokeRing antenna of HRAO IGS station

In order to find the planimetric position of the antenna, the directions tangent to the left hand side and the right hand side of the choke ring antenna were observed from all the stations of the polygonation from which the antenna was visible, i.e. 6 stations. In the adjustment, the mean direction of the two observations from a same station, was used to process the planimetric position.

The antenna height was measured by direct levelling on three different points on the top of the choke ring antenna. The mean of the three observations was corrected to account for the difference in height from the top of the choke ring to the ARP. The antenna height of the HRAO log sheet was used to get the altimetric reference point.

c. VLBI

DOMES NUMBER : 30302S001



Global view of the VLBI antenna

For the VLBI antenna, the measurement data is received at the phase centre of the receiver feed horn. The VLBI reference point is generally described as the point where the two rotation axes intersect. But for this antenna type the rotation axes do not intersect, and in this case the VLBI reference point is described as the point represented by the intersection of the fixed axis (Hour Axis) with perpendicular plane containing the moving axis (Declination Axis).

A special target was installed on the apex of the antenna quadripod, to be visible from as many survey control monuments as possible. The hour / declination mount of this antenna made the observation of the antenna difficult since the dish of the antenna hides much of the structure from view when rotating around one of the axis. The apex was the only point that could be observed from three piers during the whole required rotations of the antenna. Indeed, this target was determined by intersections from three piers with three different total stations.

The antenna was rotated around the axis to be determined, in increments of about 10 degrees, then the target described an arc of a circle around the axis of rotation. Several arcs for each axis (3 around declination axis and 2 around hour angle axis) were observed. At each increment, horizontal directions and zenithal distances were measured.

The declination axis has been observed in three different hour angle positions by rotating the antenna around the declination axis. The hour angle wheel (big wheel) was in position 0° , and the declination wheel (small wheel) went

from southern limit to northern limit by step of 10° , 14 points were observed (-85° to $+48^\circ$). The same operation was done with the hour angle wheel at $+19^\circ$ west and -25° east.

In the same idea, the hour angle axis has been observed by rotating the antenna around the hour angle axis in two different declination positions. The declination angle was held fixed on the position where zenith is achievable, and the big wheel went from western limit to eastern limit by step of 10° , 17 points were observed ($+85^\circ$ to -85°). This operation was repeated with declination angle set at 50° .

2.4.3 SAC polygon

This control network polygon includes 3 concrete piers, one temporary station on a heavy tripod, the DORIS pillar and the one IGS GPS antenna on a steel tower.

a. IGS station HARB

DOMES NUMBER : 30302M009

The directions tangent to the left hand side and the right hand sides of the choke ring antenna were observed from all the polygonation stations from which the antenna was visible, ie. 4 stations. In the adjustment, the mean of the two observations from a same station, was used to process the planimetric position.

The antenna height was measured by direct levelling on three different places under the choking antenna using reverse rod. Then, the mean of the three observations was corrected to account for the difference in height between the top of the choke ring and the ARP. The antenna height of the HARB log sheet was used to get the altimetric reference point.



ChokeRing antenna of HARB IGS station



DORIS antenna on its pier

b. D.O.R.I.S.*DOMES NUMBER : 30302S006*

The DORIS planimetric point is, for this antenna type 5Starec), a point located 88 cm above the base of the antenna, which was included in the polygonation : a target was installed on the steel pier, instead of the Doris antenna during the polygonation. A GPS antenna was also installed on the steel pier after the polygonation. The different heights were measured to 0.001m.

The DORIS altimetric point is, for this antenna, a red ring mark: 0.390 m above the base. Direct levelling was done using direct inverse rod on 3 three different points on the base of the antenna.

The eccentricity of the planimetric reference point has been also controlled.

2.4.4 GPS observations

In order to tie the two local control networks and to provide orientation, three sessions of 5 hours on three different days with a recording rate of 30s have been observed. During each session, four different stations were set up, 2 on each sub-site and at least 6 satellites were visible. The heights of the antenna were measured to 0.001m.

3 Computations**3.1 On-site validation****3.1.1 Polygon**

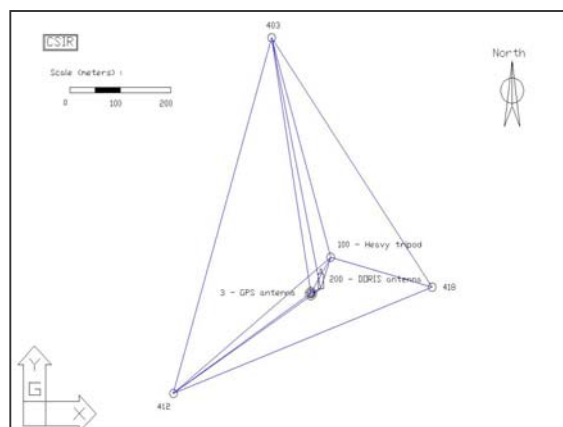
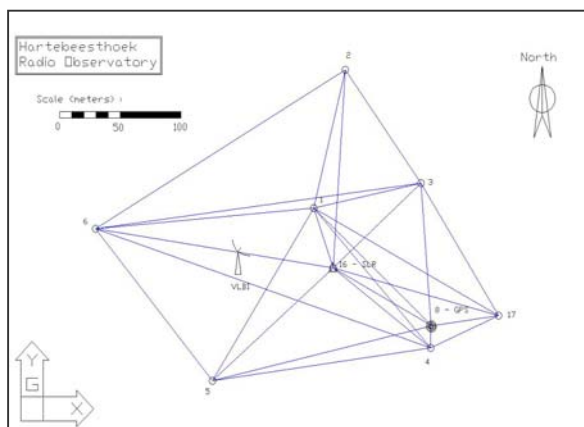
Each local control network has been pre processed on site in order to point out any problems consequently to observations. The observations have been checked in a local coordinate system by a 3D Least Squares Adjustment with the software COMP3D developed at IGN by Y. EGELS.

The blunders have been detected and the precision has been estimated in order to check if the requirements of such a survey were achieved.

The a priori standard deviations for the different observations are:

- 0.5mgon for horizontal angles,
- 0.8mgon for vertical angles,
- 1mm+1ppm for distances.

At this step, the confidence ellipsoids had their major semi-axis between 0.5 and 0.9mm for HartRAO polygon, and between 0.5 and 1.8mm for SAC polygon.



3.1.2 Levelling

The levelling network has been also validated on site by compensations between 2 successive benchmarks, then by independent compensations of the 2 subsites and the traverse between the two sites, and finally by a global compensation.

The precision was about 0.5mm for HartRAO levelling network, 0.6mm for SAC levelling network, and the global compensation achieved a 0.63mm precision.

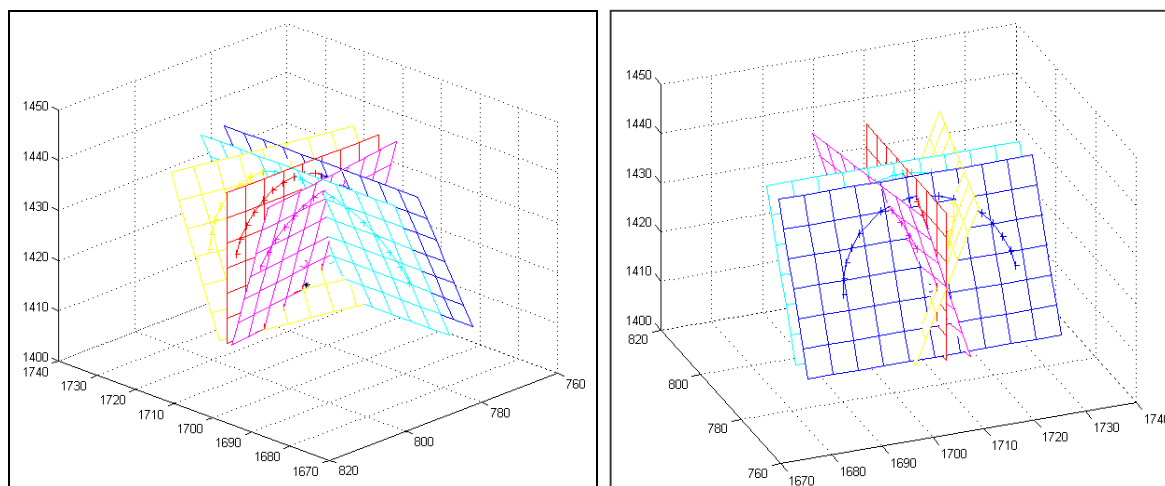
3.1.3 GPS

The GPS baselines have been processed on site to check the ambiguities resolution.

3.2 VLBI reference point

The first computations have been done in the local topocentric network that was defined by the polygon of HartRAO site. By rotating the antenna around one of the axis holding the other one blocked, the target describes an arc of a circle. The plane in which the circle is drawn is normal to the rotation axis around which the antenna is moving. This rotation axis crosses the plane in the centre of the circle.

The 5 plane and circle fittings have been computed by programs developed on the software Matlab 6.1. A first on-site program has been developed in order to check the quality of the target positions determinations and the precision to fitting a circle. Then a more elaborate program takes into account the variances-covariances matrix of the polygon and the target positions to compute the circle fittings.



2 views of the circle and plane fittings for the 5 rotations in the local topocentric network

As far as the primary axis is concerned, one arc lets the axis be determined. The problem is then over-determined since 2 arcs have been observed, which leads to a check and an evaluation of the precision.

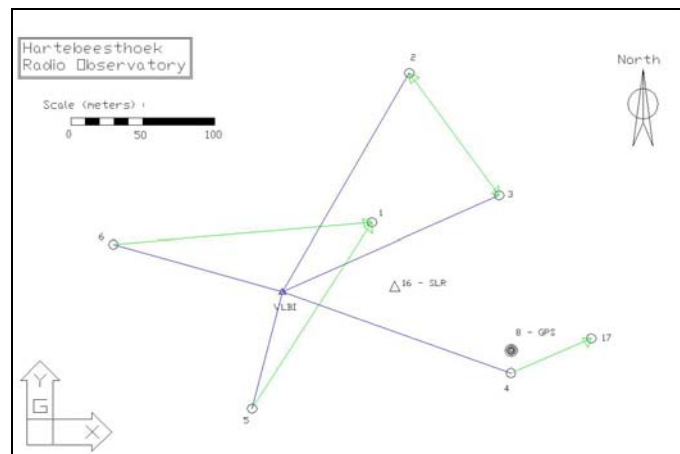
For the secondary axis, each of the 3 arcs defines a position of the secondary axis. However, the angles between each secondary planes to the primary plane have to be constant (and even right angles). Furthermore, the distance between each secondary axis and the primary axis has to be the same. Therefore, a control of the data does exist for the secondary axis too.

The VLBI reference point is the closest point of the primary axis to the secondary axis. The axis offset is the distance between the primary and secondary axis.

In order to get an idea of the precision, a Monte Carlo algorithm has been implemented. This method was used because of the lack of time to develop a full covariance matrix propagation and it gives good preliminary results.

The precision of the reference point estimated by the Monte Carlo method is 0.5mm in x-direction, 1.6mm in y-direction and 1.1mm in z-direction. The axis offset is $6.695\text{m} \pm 2.5\text{mm}$.

Given the position of the reference point and its precision, a set of fictitious observations have been computed with their associated precision. These fictitious observations correspond to fictitious horizontal and vertical angles that would be measured from the piers of the polygon to the VLBI reference point. They were introduced in HartRAO polygon.

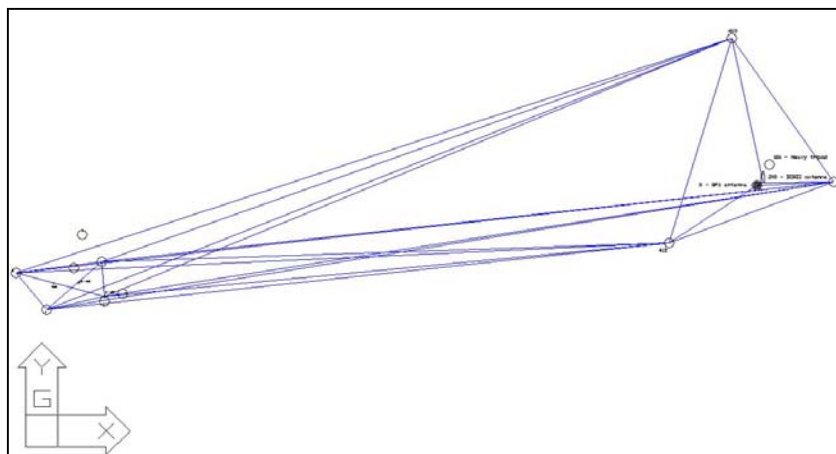


Scheme of the fictitious lines of sight

All this study has been led in HartRAO local topocentric network and Matlab 6.1. was the main developing environment.

3.3 GPS network

The GPS baselines have been processed with BERNESSE software version 4.2. The whole GPS network has been then adjusted and a full covariance matrix has been obtained. This GPS network includes 3 sessions of 5 hours. For each session, 6 points are observed at a given time: the 2 permanent stations HARB and HRAO, 2 temporary stations on HartRAO site, 2 temporary stations on SAC site.



4 Results

The whole survey has been adjusted with the software GeoLab Microsearch. The input files for Geolab were developed from all the observations: distances, horizontal and vertical angles, planimetric and altimetric centrings, levelling and GPS baselines. Therefore, all the input data can be sorted as following:

- HartRAO polygon
- HartRAO levelling
- SAC polygon
- SAC levelling
- GPS network

The adjustment has to deal with 684 observations in order to estimate 273 parameters.

Following the discussions during the workshop in Matera, the traverse run by direct levelling between the two subsites was not taken into account. Indeed, the main goal of this traverse is to set up a control network of the whole site when associated with the direct levelling of the 2 sub sites. This ground control network could be re-measured once, twice a year (or more) in order to study the local behaviour of the co-location site.

The results of the adjustment are the coordinates of all the points referring to piers, space geodetic instruments as well as their confidence ellipsoids in the ITRF 2000 at the epoch of the observations. Here is a table with the 3D confidence region at 95% of the 5 points of interest:

Microsearch GeoLab, V2001.9.20.0		GRS80		UNITS: m,GRAD Page 0051	
=====					
3D Station Confidence Regions (95.000 percent):					
STATION	MAJ-SEMI (AZ,VANG)	MED-SEMI (AZ,VANG)	MIN-SEMI (AZ,VANG)		

HARB	0.0059 (28, 90)	0.0001 (210, 0)	0.0001 (120, 0)		
VLBI	0.0046 (19, 0)	0.0026 (284, 90)	0.0024 (109, 0)		
SLR	0.0021 (24, 0)	0.0015 (294, 0)	0.0011 (126, 90)		
HRAO	0.0032 (38, 90)	0.0002 (211, 0)	0.0002 (301, 0)		
DORIS	0.0076 (55, 89)	0.0034 (234, 1)	0.0021 (324, 0)		

Furthermore the whole covariance matrix is computed and it is possible to extract covariance submatrix of the only points of interest.

A program has to be developed to express these results in the SINEX format.

This first SINEX file has been introduced into the ITRF 2000 computations by Zuheir Altamimi. The local ties, which were dubious, agree now with the ITRF 2000 solution.

Some Do's and Don't's in Terrestrial Surveying of Site Excentricities

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Abstract. Surveying tasks at space geodetic stations like eccentricity determinations or stability monitoring have to produce results which meet the one millimeter accuracy requirement of the overall global system. Although surveying procedures seem to be straight forward a number of obstacles have to be taken into account properly in order to achieve the necessary accuracy. In this paper we will address calibrations of instruments and precautions during the surveyings.

1 Motivation

At space geodetic observing stations, especially where two or more techniques are co-located, the surveying tasks related to eccentricity determinations for local ties or stability monitoring have to be considered as equally important as the observations done for the space techniques. Therefore, local surveying is a full technique in its own right and has, thus, to be taken seriously, sometimes requiring some costly investments.

The staff at space geodetic instruments should be well informed about surveying techniques and proper practices before embarking on doing local tie or stability measurements. Good advice can often be acquired from university institutions nearby with technical background like faculties of civil engineering or the like.



Fig. 1: Good example of a surveying pillar at NyAlesund Geodetic Observatory



Fig. 2: Tripod stabilized with stones at NyAlesund Geodetic Observatory

2 Instrumentation

Local surveying should ideally be carried out using fixed monumentation like surveying pillars made of concrete and reinforcement steel with forced centering devices like pillar plates or fixed 3/8" screws and height reference bolts. In order to avoid tilting of the pillar due to temperature gradients in the concrete or sun radiation, the pillar should be imbedded in a shielding either as a separate concrete ring (standard concrete pipe) or as plastic cover with insulation foam (see Fig. 1).

For temporary surveying points it is sometimes sufficient to use stable tripods which should be stabilized with bigger stones. Using tribrachs for exchanging tachymeters, reflectors and target plates is mandatory. It should be made sure that all parts of the surveying equipment are of the same forced centering system.

Tachymeters to be used should be of the highest quality available with uncertainties of at least 3 mm + 3 ppm or better (see Table 1).

Table 1: Tachymeters as of 2003

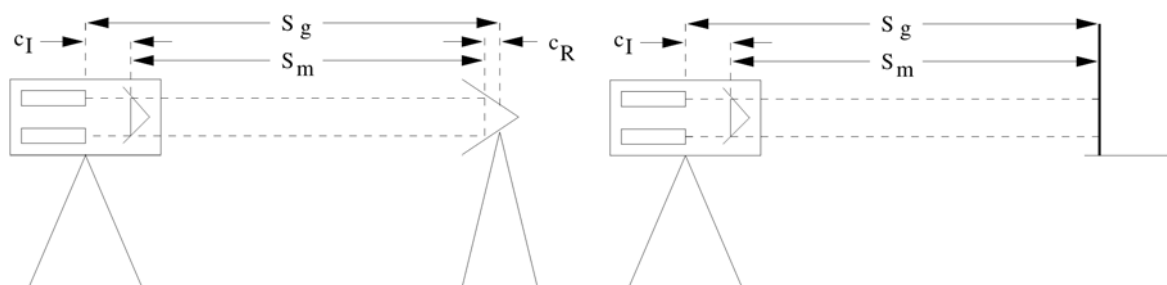
Manufacturer	Model	Display	σ dir. [mGrd]	σ distance [mGrd]	Price
Leica	TC7xx	0.2	0.6	2 mm + 2 ppm	
	TC1103	0.5	1.5	2 mm + 2 ppm	
	TCA 1800	0.1	0.3	1 mm + 2 ppm	EUR 25,000
	TCA 2003	0.01	0.15	1 mm + 1 ppm	EUR 27,000
Sokkia	SET3110 M	0.2	1.0	2 mm + 2 ppm	EUR 17,000
Topcon	GPT 1001	0.2	0.6	3 mm + 2 ppm	EUR 16,000
Trimble	3303	0.2	1.0	3 mm + 3 ppm	
	5601 DR200+	0.1	0.3	3 mm + 3 ppm	EUR 21,000
Wild	TC1600	0.1	1.0	3 mm + 3 ppm	
Zeiss	Elta S10	0.1	0.3	1 mm + 2 ppm	EUR 20,000
	Elta S20	0.1	1.0	2 mm + 2 ppm	EUR 15,500

3 Calibration of instruments

Before these instruments can be used they should be checked and calibrated. Most important is that the additive correction is determined for each instrument/prism combination in use. Figures 3 and 4 display the background of the additive corrections for prism and tape reflectors. Table 2 shows which errors may be made if these are not determined properly.

Table 2: Additive corrections of instrument/prism combinations

Prism / Instrument	AGA	Nikon	Pentax	Sokkia	Topcon	Leica	Zeiss
AGA	0	0	0	-30	0	-35	-35
Nikon	0	0	0	-30	0	-35	-35
Pentax	0	0	0	-30	0	-35	-35
Sokkia	+30	+30	+30	0	+30	-5	-5
Topcon	0	0	0	-30	0	-35	-35
Leica	+35	+35	+35	+5	+35	0	0
Zeiss	+35	+35	+35	+5	+35	0	0



Figures 3 and 4 display the background of the additive corrections for prism and tape reflectors.

Table 3 indicates which other errors may be encountered with tachymeters. Cold start and temperature drift effects of additive correction should also be taken into account. This can largely be avoided if the instrument has sufficient time to accommodate to the outside temperature.

Table 3: Instrumental errors

scaled by distance

modulation frequency	$10^{-6} - 10^{-7}$
refraction/ meteorology	$1 \text{ K} \equiv 1 \times 10^{-6}$
	$4 \text{ HPa} \equiv 1 \times 10^{-6}$

independent of distance

integer cycles	free of error
phase	cyclic / inhomogenous negligible
additive correction	0 – 35 mm

4 Measurements

For the actual measurements one should select a day which is favourable in terms of the weather. It should be stable, i.e. large temperature variations should be avoided. Optimal conditions prevail if the day is hazy with little wind. Rapid changes of sunshine and cloud occultation should be avoided. An umbrella over instrument should be set up in any case and over the reflector if possible.

The handling of the instrument should be given some consideration.

1. Permit acclimatisation of instrument
2. Permit warm-up period
3. Measure temperature at instrument and reflector
4. Measure pressure at instrument (and at reflector if there is a large height difference)
5. Enter meteorological parameters into the instrument only once (apply incremental corrections in data reduction process)
6. Set additive correction in instrument to zero (apply corrections in data reduction process)

Co-location Surveys & Results in GSI's Space Geodetic Network

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Abstract. We report on the present results of our co-location surveys at our domestic VLBI network sites and a preliminary comparison of VLBI and GPS solutions on a baseline between Tsukuba and Shintotsukawa. The comparison shows no systematic differences exceeding 10^{-8} between the two techniques. The biggest errors in co-location surveys lie in coordinate transformation process to align the local tie-vector to a global one.

1 Introduction

Geographical Survey Institute (GSI), Japan has established and maintains nationwide space-geodetic networks consisting of 4 VLBI stations and 1,200 GPS tracking sites (GEONET: GPS Earth Observation NETwork), see Figure 1. Accurate tie information is indispensable for the maintenance of the high-precision terrestrial reference frame and it is true for our new geodetic system (JGD2000) as it is based on the fundamental network consisting of VLBI and GPS. In the establishment of JGD2000, we mainly used local GPS observations to connect the accuracy of the ties was estimated as 5mm for the horizontal and 20mm for the vertical component [6].

As the precision of space geodetic measurement improves, co-location should be established with same as or better than the accuracy of these techniques and for more precise ties, we adopted a conventional survey method to connect reference points of VLBI and GPS. This is the report of our co-location surveys to improve our space-geodetic ties in the new geodetic coordinate system. A brief introduction of method and procedure of our local surveys is described in section 2. To check the results in section 3, preliminary comparison was made between the time series of baseline solutions in section 4.

2 Method of local-tie

For GPS and VLBI connection, conventional terrestrial survey method was chosen for the 3D positional determination of reference points. Specifically, we made electro-optical measurements for distance and angles and/or leveling observations. In a small local network conventional survey could yield mm-accuracy (Figure 2).

2.1 Procedures

We took the following procedures:

- Establishment of permanent ground monuments
- Network survey of the monuments
- Determination of space-geodetic reference points from the ground monuments around them.
Reference point was defined as:
 - for VLBI, intersection of azimuth and elevation axis (the center of a spherical shell on which a target on the antenna traces as the antenna points to various directions);
 - for GPS, designated position on the antenna, phase center calibration will be done by GPS analysis software.
- Alignment of local tie vector to a global frame (see [3] for details)

Network for local-tie at GSI Tsukuba between VLBI32m and TSKB(IGS)

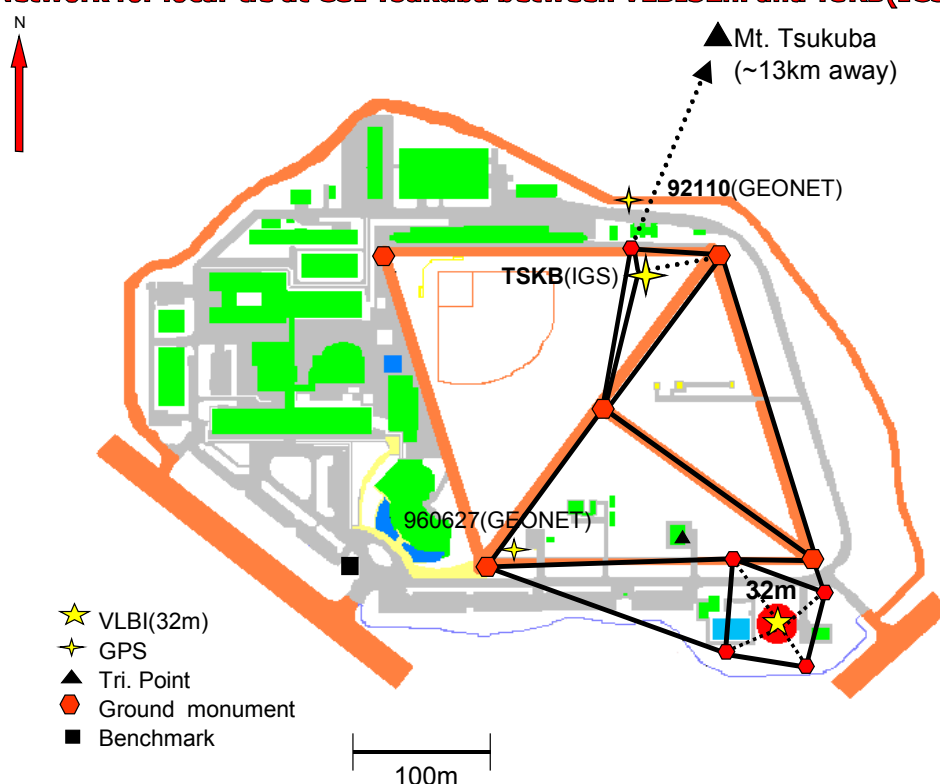


Fig. 2: Local Network at Tsukuba VLBI station

2.2 Alignment of the tie vector to a global frame

To be used in a comparison or integration of multi techniques, a local vector must be transformed into a global reference system. Specifically, the orientation and vertical direction of a local network should be known. We made GPS observation for orientation and used deflection of the vertical from past astronomical observations. Alternatively 7 parameters in Helmert transformation could be obtained only by GPS observations, which we did not adopt here.

We think the biggest errors would be introduced here in the transformation process from local to global coordinates although GPS observation was a typical 24-hour session for precise surveying. GPS errors could be as big as a few cm due to environmental situation or statistical variation as the time series solutions of continuous GPS network show. Continuous or multi-day observations will be necessary to get highly reliable GPS vectors for transformation.

3 Results

Connection of reference points by ground survey yielded a precise tie at each of the three stations in a local system (Table 1).

Table 1. Determination of reference positions

rms (mm)		Shintotsukawa-3.8m	Tsukuba-32m	Aira-10.3m
3D positions of ground monuments		1-2	0-1	1-4
VLBI reference position	3D	0.7	0.2	0.5
	Radial component	1.0	0.6	0.3

We could see VLBI references were determined very well and each antenna structure was rigid enough to show no noticeable axis offsets.

For transformation of the local relative vector to global ITRF system, we made GPS observations between the network and a direction maker 7-13km away from the site to determine the network's horizontal orientation and used the deflection of the vertical at the site. For the deflection of the vertical, we used the value obtained by astronomical observations at Tsukuba (1980-1983) and interpolated one from Japan's Geoid model (GSIGEO2000, [3]) at Shintotsukawa. The interpolation was compared with several sites with observed values and considered good enough for the transformation.

4 Comparison of domestic VLBI and GEOENT GPS solutions

Two sets of time series solutions were compared on the baseline vector from GEONET 92110 (Tsukuba) to 942001 (Shintotsukawa). VLBI solutions were converted to the GPS baseline with simple vector additions as depicted in Figure 3. Analysis system was Calc/Solve for VLBI and Bernese for nationwide GPS network [1]. Figure 4 shows the two sets of solutions from 1995 to 2003 for each component of the vector. No artificial offset between the two series was added. In horizontal components no systematic differences exceeding a few cm are seen. In contrast, the vertical series differ by a few cm or more and we'll need to investigate what causes this discrepancy. Possible causes are, simple error of calculation, snow on GPS antenna, local site-specific effects, etc.

5 Conclusions and future works

An accurate local-tie was established at 3 of 4 GSI VLBI sites in Japan. Co-location survey will be completed in 2004-5 if the remaining Chichijima site is co-located. Now that domestic VLBI experiment has tripled its frequency (once per month in 2003) and time series solutions will be a reference for Japan's geodetic network by comparing and combining with daily GPS solutions.

Connections of VLBI and GPS reference points were established at sub-mm level by conventional surveying method. There still remain more than a few mm uncertainties when it comes to align the local vectors to a global frame due mainly to the uncertainties of GPS observations. We should increase the number of GPS observations for taking data for a few to ten days.

Preliminary comparison of VLBI and GPS time series solutions showed the relative differences are smaller than 10^{-8} on an 840km baseline of our VLBI network for horizontal components and length, whereas the height components differ significantly than expected from the internal consistency and we should re-check the comparison process and clear the possible reasons.

Investigation on smaller geophysical, meteorological and environmental effect on site positions becomes more important than ever as we further pursue the improvement of space geodetic observation. We will have to look into antenna thermal deformation, various loading effects and site specific environmental effect, see ex. [5] and [6] for the case of Tsukuba.

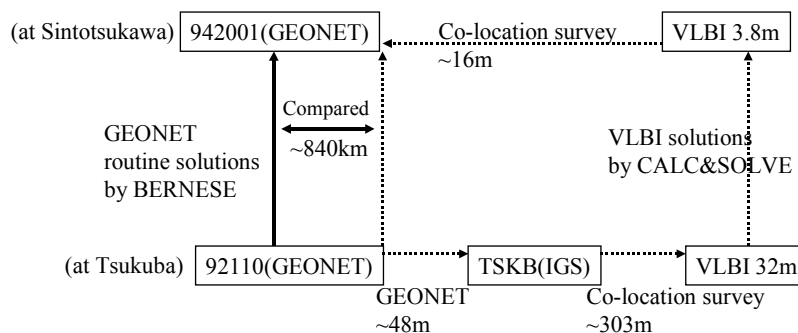


Figure 3. Comparison of domestic VLBI and GEONET GPS solutions.
GEONET and VLBI+co-location solutions were compared
on the baseline vector (942001-92110)

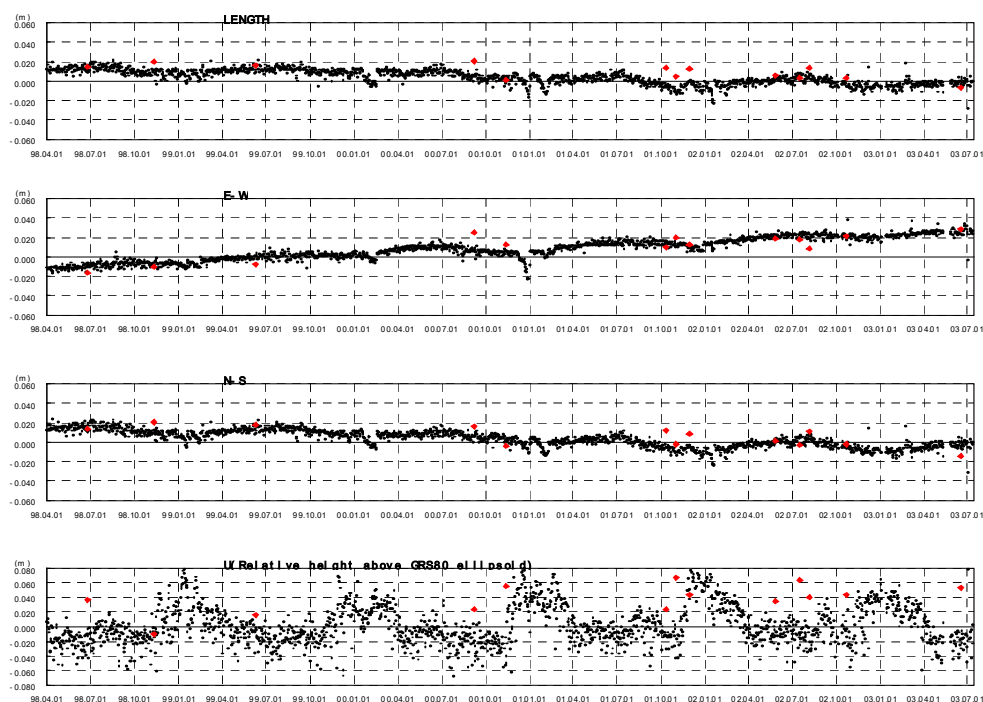


Figure4. TSUKBA-SINTOTSUKAWA baseline vector Time Series
(GPS •, VLBI ♦)

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Terrestrial Data Analysis and SINEX Generation

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With contributions of John Dawson and Patrick Sillard

Abstract. This position paper focuses on the computation of local ties between co-located space geodetic instruments using terrestrial data, and on SINEX generation. We address also some important aspects related to the Reference Point (RP) definition for the various instrument types, i.e. VLBI, SLR, GPS and DORIS. The main issue is related to the data analysis of the terrestrial data, and to the generation of the final SINEX files, which should contain the full variance covariance matrix for the local ties. Finally, we provide recommendations regarding local tie determination and the documentation of the results.

1 Introduction

Co-locations and local ties (intra-site vectors) between the space geodetic instruments are a key element for integrating the reference frame results from the different techniques, such as VLBI, SLR, GPS and DORIS. Both, the current situation regarding distribution of co-location sites and accuracy of local ties is not satisfying. Furthermore, the ITRF2000 results indicate that there are a number of dubious or erroneous local ties (Altamimi et al., 2002, Altamimi, 2005). Discrepancies between local ties and the space geodetic solutions were also identified at DGFI using the results of TRF computations (Angermann et al., 2004, Krügel and Angermann, 2005). An interpretation of the existing discrepancies is difficult since various factors have to be considered, such as systematic biases between space geodetic solutions, local site dependent effects, errors in local ties, remaining inconsistencies related to the datum definition. Regarding a better separation of these effects and to identify still remaining technique-specific systematic biases, the local ties between co-located instruments should be determined with the highest possible accuracy. This is also very important to fully exploit the unique capabilities and the individual strengths of the different space techniques.

To achieve this high accuracy requirement for the local ties various issues need to be addressed, including the design of the local network, the instrumentation and technical equipment, the surveying methodology, the realization of the reference points for the various instrument types, computational and software-related aspects, transformation of the local network into the global frame, documentation of local surveys and representation of final results in SINEX format.

This position paper concentrates on issues related to the data analysis and the SINEX generation, the other topics mentioned above are primarily addressed in other sessions of this workshop. A key issue in precise local tie determination is the definition and realisation of the reference point for the different instrument types, which is addressed in Chapter 2. In Chapter 3 some specific observational aspects are presented. Computational issues (software, estimation models, analysis strategy), including the generation of a complete correlation matrix corresponding to the intra-site vector are addressed in Chapter 4. Finally, the documentation and representation of local tie results in SINEX format are presented in Chapter 5.

2 Aspects related to Reference Point definition

A fundamental aspect that must be taken into account when performing a local tie determination is the physical definition of the Reference Point (RP) of each space geodetic technique. In principle, there are two different types of instruments, those with mechanically moving parts to control the direction of data acquisition (VLBI and SLR), and those with radio-frequency antennas simultaneously sensitive to signals from all directions (GPS and DORIS).

VLBI: The RP is defined as the intersection of the fixed axis with the orthogonal plane to it, containing the moving axis (Ma 1978). This definition takes into account the possible presence of an offset and applies to all kinds of VLBI telescopes. Nevertheless, it isn't general enough because it does not take into account the possible presence of a fixed skew angle (i.e.: a lack of orthogonality between the fixed and the moving axis): in this case, the plane containing the moving axis does not exist. The RP is generally defined as the point on the fixed axis having minimum distance from the moving axis.

In practice, the observations performed to several calibrating radio sources at different frequencies, allow the estimates of eight parameters that are related to the general telescope orientation and to its deformation due to gravitational and other loading effects. These parameters have an impact on the azimuth and elevation pointing angles. In this case, also the skew error is taken into account. Its estimated value at different observing frequency can change considerably (up to 0.03 gon) while, in principle, it should remain constant. Terrestrial observations of the VLBI telescope aiming to RP determination might have an impact on the determination of some of these relevant parameters and would therefore represent a precious source of information offering the possibility to constraint their values.

There are practically three different approaches that are currently used for recovering the position of the VLBI RP:

1. Direct approach: on some VLBI telescopes the RP is materialized using a target and it is observed as all the other points that form the local network. The RP is therefore estimated straightforwardly in the terrestrial data adjustment. It is clear that, using this so-called "direct" approach, no information related to the telescope orientation/deformation can be recovered. Furthermore, since the materialized point is not connected to the physics of observations, it is unlikely that it is identical to the real RP.
2. Hybrid approach: it is represented by the physical materialisation of the rotational axes using appropriate targets (Nothnagel et al., 2002). Observations of these targets during rotational sequences allow the determination of the RP provided that they represent the rotational axes. With this "hybrid" approach no information on the fixed axis and moving axis orientation will be available. Furthermore, no information on VLBI antenna deformation can be recovered (but, at the same time, deformations will most likely not affect the measurements). The accuracy of other relevant unknown VLBI telescope's structure characteristics (e.g. skew angle, offset, tilt angle) will depend on how accurately the elevation axis is materialized and represented by the targets.
3. Indirect approach: it is based on the definition of the axes (i.e.: the RP) through the observation of rotational sequences of targets widely and opportunely installed on the antenna structure (Dawson and Johnston, 1999; Sarti et al., 2000). This "indirect" approach uses geometrical considerations to constraint the positions of the targets and will be heavily affected by gravitational deformations of the radio telescope structure, and consequently aims at realising the physical definition of the RP from

terrestrial measurements techniques. At the same time it is very flexible, offering the possibility to estimate the tilt of the fixed axis, the skew angle and other desired parameters. In principle, there is the possibility to superimpose a finite element deformation model of the antenna structure to the target positions estimate for a more accurate determination of the sought VLBI RP.

The need of investigating the structural antenna models and the delay corrections introduced in VLBI data analysis is a very important subject that must be studied and possibly linked to terrestrial data analysis in order to ensure a reasonable, efficient and consistent computation of the RP based on terrestrial observations.

SLR-LLR: the RP is defined, similarly to the VLBI case, as the intersection of the two axes of the telescope: the fixed axis and the moving axis. The RP definition is, for the indirect methodology mentioned above, equivalent to the VLBI one. It is therefore possible to apply this approach to SLR-LLR telescopes with no major changes. The hybrid methodology could, in principle, be applied too. The materialisation of the axes would in this case be more dependent on the design of the telescope. There is no possibility of applying the direct methodology at SLR-LLR telescopes because the RP is inaccessible.

GPS and DORIS: for these two techniques, the RP is a physical point in the antenna such as the bottom of the amplifier housing of the ground plane, the so-called Antenna Reference Point (ARP). In principle, the RP definition for GPS and DORIS is equivalent and it is based on the external structure of the antenna. The ARP may directly be the tracking point of the system or may be related to a physically materialized geodetic marker using an eccentricity vector. The survey of DORIS and GPS ARP can be performed using an indirect approach, triangulating the external shape of the antenna (Sarti et al. 2004). This approach requires no removal of the antenna and is particularly useful in permanent networks where the tracking point has been chosen to be the ARP itself. Simple geometrical considerations are chosen and applied for ARP computation. If the tracking point is an external geodetic marker, a direct approach is used: a target is linked to the marker and observed. A combination of the two approaches allows the precise determination of the *intra-technique eccentricity* (i.e. the eccentricity between the technique-related geodetic marker and the RP) which, for almost all GPS sites, is expected to remain stable in time. This is not the case for most of the DORIS tracking systems, where the antenna is placed on a mast and the geodetic marker can be missing.

Recommendation 1: A clear definition of RPs should be developed by the analysis communities for each space geodetic technique.

Recommendation 2: An external geodetic marker exists for each technique. An accurate intra-technique eccentricity should be re-estimated every time the local tie survey is performed regardless the RP coincides with the tracking point or not.

Recommendation 3: The space geodetic analysis and local tie analysis community (e.g. the newly created IERS working group on local ties, all local survey groups) should develop new local tie products for use in analysis (e.g.: skew angle, tilt angle, wobble, structural deformations).

3 Ground observations

Taking into account the high accuracy requirement of 1 mm for local tie determination, the issues related to site surveys for co-locations are extremely important, including the design of the local network, planning and strategies

for ground observations, site monumentation and local control networks, monitoring local site stability, surveying methods and technical equipment. All these issues are addressed in session 2 “Site Surveys” of this workshop.

A few specific remarks related to ground observations and network design are provided below:

- **Technical aspects:** It is important that properly calibrated high precision instrumentation and high precision devices should be extensively used in order to ensure accurate results.
- **Design of local network:** This is a very important aspect since the design of the network directly influences the correlation matrix associated to the eccentricity vector estimate. Different choices operated on the geometry of the observations considerably affect the correlations between the components of the space geodesy RP techniques (Sarti et al. 2004).
- **Terrestrial observations:** The measurements of angles and distances, along with height differences, are used to adjust the local network and estimate target positions. The relevant corrections that must be taken into consideration for an accurate terrestrial data processing are refraction and geoid undulation.

Recommendation 4: High precision instrumentation and devices should always be adopted. Minimum requirements on instrumentation and measurement redundancy should be set.

Recommendation 5: A priori simulations of terrestrial observations should be undertaken so as to assess the impact of different survey designs.

4 Computation

This chapter concentrates on several aspects related to the adjustment of the local networks in order to provide accurate local tie results. This topic was the major focus of this session “Analysis and SINEX” of this workshop. Examples of site surveying and eccentricity vector estimation at different co-location sites were presented during this workshop (see e.g. Dawson et al., 2005; Johnston et al., 2005; Michel et al., 2005; Schlüter et al., 2005; Vittuari et al., 2005). These examples provide an overview of the wide spectrum of this topic, which is demonstrated also by other publications (e.g. Kanao et al., 1995; Dawson and Johnston, 1999; Johnston et al., 2000; Long and Bosworth, 2000; Sarti et al., 2000; Tomasi et al., 2001; Nothnagel et al., 2002). Thus, it is obvious that the situation regarding site surveys and computation of local ties is very much dependent on the specific approach applied when measuring the RP and on specific conditions at a co-location site, and it is not therefore easy to provide general guidelines and recommendations. Furthermore, it should be considered, that there are various groups involved in site surveys, using a wide variety of software for adjusting the local networks (e.g. Microsearch Geolab, STAR*NET, PANDA, CREMER, ...), and applying different computation methodologies. This clearly shows that there are (at present) no common standards or recommended procedures for computing local ties.

The idea of this position paper is to address some aspects related to this topic in order to stimulate discussions between the relevant groups, and to make some recommendations for future improvements:

- An important question is the realization of the Reference Point for different space geodetic instrument types. In particular, there is no unique choice that can be operated on the geometrical constraints applied in the indirect approach. They will most probably have an effect on the final es-

timate and the associated correlation matrix. It is therefore important to plan an *ad hoc* survey at a representative co-location site and measure the eccentricity vectors. The data should be collected with the intention of producing a common dataset on which all the available post-processing software based on the indirect methodology can run and estimate the surveyed eccentricities. The same considerations apply to the hybrid survey approach, where the axis are materialized: different procedures should be compared;

- A sufficiently sophisticated modelling of relevant effects must be ensured: it has to be possible to take into account refraction and deviation of the vertical and therefore produce an accurate estimate of the positions of surveyed targets;
- A number of questions related to the computation methodology (e.g. weighting of different observation types, transformation of local network into the global frame, datum definition of the local ties) need to be studied;
- A survey of software used for the local network adjustment should be initiated.

The issues mentioned above should be addressed by the recently created IERS working group on co-locations in cooperation with other relevant groups, i.e. the ITRF combination centres, analysis and technique centres of the different space techniques, etc.

Recommendation 6: Survey and comparison of different software systems used for the adjustment of local networks (definition of a suitable pilot project) should be performed.

Recommendation 7: A common data set on a representative co-location site should be provided to compare the direct, hybrid and indirect approaches to RP determination.

5 Documentation and SINEX generation

The topic of local survey documentation was addressed in session 4 “reporting” of this workshop. A draft version of a standard documentation called “Local surveys document for co-located space geodetic techniques within the International Terrestrial Reference Frame” was discussed concerning content, the level of detail, the organization and the format (see contributions of session 4, this volume).

In this position paper we focus on the representation and documentation of the final local tie results, which should be done in the Solution INdependent EXchange format (SINEX) for space geodesy. A consistent format description for all space geodetic techniques is available, i.e. SINEX 2.00¹. Examples for local tie SINEX files are also available, i.e. the local ties used for ITRF2000 computation², and local survey results of the Australian Surveying and Land Information Group, AUSLIG (see attached SINEX file for the co-location site Yaragadee as an example). The local survey results for all co-location sites should be available in SINEX format. In addition, also the exchange of local survey terrestrial observations is of great importance for promoting a comparison of different software. Datasets containing the terrestrial observations should be available for computation and processing by all the groups interested in estimating eccentricity vectors. For this purpose clearly stated standards are needed.

¹ see <http://alpha.fesg.tu-muenchen.de/iers/sinex/format>

² see ftp://lareg.ensg.ign.fr/pub/itrf/itrf2000/tiesnx/*.SNX

Concerning the final generation of local tie SINEX files there are remaining open issues, which need to be addressed within the space geodesy community and in particular within the recently created IERS working group on site co-locations. Important aspects include:

- Contents of the SINEX files: It should contain the largest amount of information concerning the local network in order to compare the stability of the site from one local survey to the other. The full variance covariance matrix should be available, also the submission of unconstrained normal equations is recommended. It should be agreed, which SINEX blocks are mandatory.
- Reference frame for local tie results: In principle, the results could be provided in an arbitrary local frame, or it is possible to exchange the coordinates in a global frame (e.g. ITRF). How the mapping in the global frame should be done is an open issue. GPS observations should provide a reliable and (sub-millimetre) accurate orientation via the IGS satellite orbits. The scale of the local network should be defined precisely by the terrestrial observations and GPS. How the reference frame should be defined also depends on the way data are used afterwards. Important is, that any constraints applied to the local network adjustments will be completely reported in the SINEX files.
- Time stability of local ties: Control measurements at co-location sites are important to detect any changes in the local ties, i.e. after a large earthquake in the vicinity of a co-location site (e.g. Arequipa, Peru) a re-survey of the local ties is mandatory. A major question regarding the documentation of local tie results is, how possible site depending effects should be considered in the SINEX files, i.e. constant local ties for a defined time period, or even time dependent local ties.

Recommendation 8: Standards on raw terrestrial data archiving and sharing must be developed.

Recommendation 9: There should be an agreement on the type and number of stations to be included in SINEX.

Recommendation 10: There should be an agreement on the reference frame in which the local ties are expressed and how they are mapped into this reference frame.

Recommendation 11: There should be an agreement on the generation of SINEX files: (e.g.: which blocks should be mandatory, the submission of unconstrained normal equations is recommended).

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Appendix: SINEX file of local ties at co-location site Yaragadee, provided by the Australian Surveying and Land Information Group (AUSLIG)

```

%=SNX 1.00 AUS 00:087:00000 AUS 98:234:00000 98:237:00000 C 00018 0 X
*-----
* SOLUTION INDEPENDANT EXCHANGE FORMAT (SINEX) FOR SPACE GEODESY.
* - SINEX VERSION 1.00
* - FILE CREATED BY PROGRAM SINEX_LT V1.0
* - TECHNIQUE IS COMBINED GPS AND TERRESTRIAL (C) - LOCAL TIE SURVEY
* - SINEX FILE FOR LOCAL TIE SURVEY AT YARAGADEE SLR STATION
* - SOLUTION COMMENTS
*-----
+FILE/REFERENCE
DESCRIPTION      Australian Surveying and Land Information Group
OUTPUT           AUSLIG LOCAL TIE SURVEYS
CONTACT          jimsteed@auslig.gov.au
SOFTWARE         SINEX_LT V1.0
HARDWARE         HP 735
-FILE/REFERENCE
*-----
+FILE/COMMENT
-FILE/COMMENT
*-----
+INPUT/HISTORY
*O FM VER  AGY TIME_STAMP  DAT DATA_START  DATA_END  T PARAM C TYPE
=SNX 1.00 AUS 00:087:00000 AUS 98:234:00000 98:237:00000 C 00018 0 X
-INPUT/HISTORY
*-----
+INPUT/FILES
*AGY TIME_STAMP  FILE_NAME  DESCRIPTION
AUS 00:102:00000 AUS00C04.SNX  YARAGADEE LOCAL TIE SINEX FILE
-INPUT/FILES
*-----
+SITE/ID
*CODE PT  DOMES  T STATION DESCRIPTION  APPROX_LON  APPROX_LAT  APP_H
YAR1  A 50107M004 C Yaragadee, IGS GPS  115 20 49.1 -29 02 47.7 241.3
YARR  A 50107M006 C Yaragadee, IGEX GPS  115 20 49.1 -29 02 47.7 241.4
YARA  A 50107S006 C Yaragadee, DORIS  115 20 48.0 -29 02 46.9 243.4
7090  A 50107M001 C Yaragadee, SLR Gd Mk 115 20 48.2 -29 02 47.3 241.4
YIVP  A 50107S007 C Yaragadee, SLR  115 20 48.2 -29 02 47.3 244.5
YARB  A 50107S010 C Yaragadee, DORIS  115 20 48.0 -29 02 46.9 243.7
-SITE/ID
*-----
+SOLUTION/EPOCHS
*CODE PT SOLN T DATA_START DATA_END MEAN_EPOCH
YAR1  A 1 C 98:234:00000 98:237:00000 98:236:00000
YARR  A 1 C 98:234:00000 98:237:00000 98:236:00000
YARA  A 1 C 98:234:00000 98:237:00000 98:236:00000
7090  A 1 C 98:234:00000 98:237:00000 98:236:00000
YIVP  A 1 C 98:234:00000 98:237:00000 98:236:00000
YARB  A 1 C 98:234:00000 98:237:00000 98:236:00000
-SOLUTION/EPOCHS
*-----
+SOLUTION/STATISTICS
* STATISTICAL PARAMATER  VALUE(S)
VARIANCE FACTOR(S)      0.112453681147372E+01
NUMBER OF OBSERVATIONS  1153
NUMBER OF UNKNOWNNS     957
NUMBER OF DEGREES OF FREEDOM 196
-SOLUTION/STATISTICS
*-----
+SOLUTION/ESTIMATE
*INDEX TYPE CODE PT SOLN REF_EPOCH UNIT S ESTIMATED VALUE STD_DEV
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```

```

2 STAY YAR1 A 1 97:001:00000 m 0 0.504331688400000E+07 .999368E-04
3 STAZ YAR1 A 1 97:001:00000 m 0 -.307853075150000E+07 .999761E-04
4 STAX YARR A 1 97:001:00000 m 2 -.238902449710000E+07 .240133E-03
5 STAY YARR A 1 97:001:00000 m 2 0.504331536940000E+07 .412211E-03
6 STAZ YARR A 1 97:001:00000 m 2 -.307853417590000E+07 .267741E-03
7 STAX YARA A 1 97:001:00000 m 2 -.238900389310000E+07 .390373E-03
8 STAY YARA A 1 97:001:00000 m 2 0.504334061380000E+07 .418022E-03
9 STAZ YARA A 1 97:001:00000 m 2 -.307851310370000E+07 .427080E-03
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14 STAY YIVP A 1 97:001:00000 m 2 0.504333185350000E+07 .124162E-02
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16 STAX YARB A 1 97:001:00000 m 2 -.238900402380000E+07 .511243E-03
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+SOLUTION/APRIORI
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3 STAZ YAR1 A 1 97:001:00000 m 0 0.307853075150000E+07 .100000E-03
4 STAX YARR A 1 97:001:00000 m 2 -.238902449710000E+07 .000000E+00
5 STAY YARR A 1 97:001:00000 m 2 0.504331536940000E+07 .000000E+00
6 STAZ YARR A 1 97:001:00000 m 2 0.307853417590000E+07 .000000E+00
7 STAX YARA A 1 97:001:00000 m 2 -.238900389310000E+07 .000000E+00
8 STAY YARA A 1 97:001:00000 m 2 0.504334061380000E+07 .000000E+00
9 STAZ YARA A 1 97:001:00000 m 2 0.307851310370000E+07 .000000E+00
10 STAX 7090 A 1 97:001:00000 m 2 -.238900692030000E+07 .000000E+00
11 STAY 7090 A 1 97:001:00000 m 2 0.504332935270000E+07 .000000E+00
12 STAZ 7090 A 1 97:001:00000 m 2 0.307852491100000E+07 .000000E+00
13 STAX YIVP A 1 97:001:00000 m 2 -.238900812440000E+07 .000000E+00
14 STAY YIVP A 1 97:001:00000 m 2 0.504333185350000E+07 .000000E+00
15 STAZ YIVP A 1 97:001:00000 m 2 0.307852646190000E+07 .000000E+00
16 STAX YARB A 1 97:001:00000 m 2 -.238900403270000E+07 .000000E+00
17 STAY YARB A 1 97:001:00000 m 2 0.504334083410000E+07 .000000E+00
18 STAZ YARB A 1 97:001:00000 m 2 0.307851321820000E+07 .000000E+00
-SOLUTION/APRIORI
*-----
+SOLUTION/MATRIX_ESTIMATE U COVA
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1 4 0.99960106869771E-08 0.17068267241602E-10 -0.32457503774402E-10
1 7 0.9905193541002E-08 0.68938990952656E-11 0.29982566719221E-11
1 10 0.10014718352022E-07 0.17169732312250E-10 -0.18277628307036E-11
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1 16 0.10508579916140E-07 0.12896991070381E-09 -0.24692672835713E-09
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3 18 0.96796601566017E-08
4 4 0.57663718733818E-07 -0.69339609527378E-07 0.40497988502278E-07
4 7 0.10754823058586E-07 0.16148811492324E-08 0.18590251867944E-08
4 10 0.14970237042238E-07 0.44327683542601E-08 0.29189917036896E-08
4 13 0.99660106869758E-08 0.71752841824734E-10 -0.44096816963527E-10

```

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6     9  0.15704409300248E-07 -0.34794490295517E-08  0.73520553987879E-09
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11    17  0.14057792654436E-07  0.25110340239799E-07
12    12  0.13536701931872E-06 -0.18277628257240E-11  0.38960815712452E-11
12    15  0.99976172093652E-08 -0.70339648598844E-07  0.10579313928642E-07
12    18  0.81028822160330E-07
13    13  0.14815870116928E-05 -0.67834463531245E-06 -0.86045631900540E-06
13    16  0.10508579916160E-07  0.12896991052625E-09 -0.24692672836176E-09
14    14  0.15416080839639E-05  0.39709046886359E-06 -0.10735797448866E-08
14    17  0.97276550737121E-08  0.52131777419854E-09
15    15  0.12445853060369E-05  0.65976496384522E-09  0.16732432463000E-09
15    18  0.96796601566024E-08
16    16  0.26136946171794E-06 -0.86585708316172E-07 -0.58789214044583E-07
17    17  0.19863269594678E-06 -0.27134015587172E-07
18    18  0.22972797582782E-06
-SOLUTION/MATRIX_ESTIMATE U COVA
*-----
+SOLUTION/MATRIX_APRIORI U COVA
*PARA1 PARA2 PARA2+0 PARA2+1 PARA2+2
1 1 0.100000000000000E-07
2 2 0.100000000000000E-07
3 3 0.100000000000000E-07
-SOLUTION/MATRIX_APRIORI U COVA
*-----
%ENDSNX

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The Determination of Telescope and Antenna Invariant Point (IVP)

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1 Introduction

The development of multi-technique International Terrestrial Reference Frames such as ITRF2000 (Altamimi, 2002) has focussed attention on the need to precisely measure and express the local terrestrial connection between each of the complimentary space geodetic observation systems, such as GPS, GLONASS, SLR, VLBI and DORIS, at co-located geodetic observatories. Somewhat complicating this endeavour has been the difficulty of defining and measuring the relationship between the measurement reference points for each of the techniques. This is particularly the case for the SLR and VLBI observing systems where the reference point, sometimes referred to as the invariant reference point (IVP), is in general not able to be directly observed.

At Geoscience Australia an approach has been developed for estimating the observation reference point of such systems using an indirect technique of coordinating targets on the measurement systems during specific rotational sequences of the telescope/antenna system. Using a geometrical model the characteristics of the rotational axes, which importantly include their position and orientation in an arbitrary local geodetic datum, and the position of the invariant reference point can be estimated. This approach utilises full variance-covariance information of the target and local reference geodetic network and does not assume target symmetry about the final system reference point, idealised axis orientation (i.e. axis verticality/horizontality), axes orthogonality or precise intersection. Local terrestrial connections of an accuracy of 1mm (in the local frame) are routinely observed and computed between the GPS, VLBI, SLR, GLONASS and DORIS systems located in Australia, at Tidbinbilla, Yarragadee, Hobart and Mount Stromlo.

2 IVP determination

In the general case for both SLR and VLBI the IVP cannot be directly measured and must be determined indirectly by observation to targets on the system structure during rotational sequences. A rigorous least-squares analysis that utilises all target coordinates and their variance-covariance information can then be used to determine the system IVP.

There are three common system type characteristics, namely azimuth/elevation systems (fixed vertical axis); X/Y systems (fixed horizontal axis) and HA/DEC systems (fixed axis points to the celestial pole). Somewhat complicating reference point determination for many systems is

- the fixed (or primary axis) and the moving (or secondary axis) axis may not intersect (and are in some cases many metres apart, see Fig. 1);
- the system's structural design can constrain the visibility and hence the number and network design of line of sight observations;

- observations are generally made from below up onto the systems structure therefore limiting network design;
- often there are domes covering the structure that significantly limit visibility; and
- many system have limited rotational freedom reducing the reliability of axis determination.

3 Survey Accuracy

In order to make a significant contribution to the space geodetic technique comparison the accuracy of the local survey should match/better accuracy of the space geodetic techniques. At present a carefully observed terrestrial survey has an accuracy of around 1 mm in the local frame, however aligning a local survey to a global reference frame cannot be completed at the 1 mm level. A total error budget for a fully aligned local tie survey at the 3 mm accuracy level seems at this time achievable.

At Geoscience Australia classical geodetic observations including slope distance and vertical/horizontal angles and precise differential levelling are

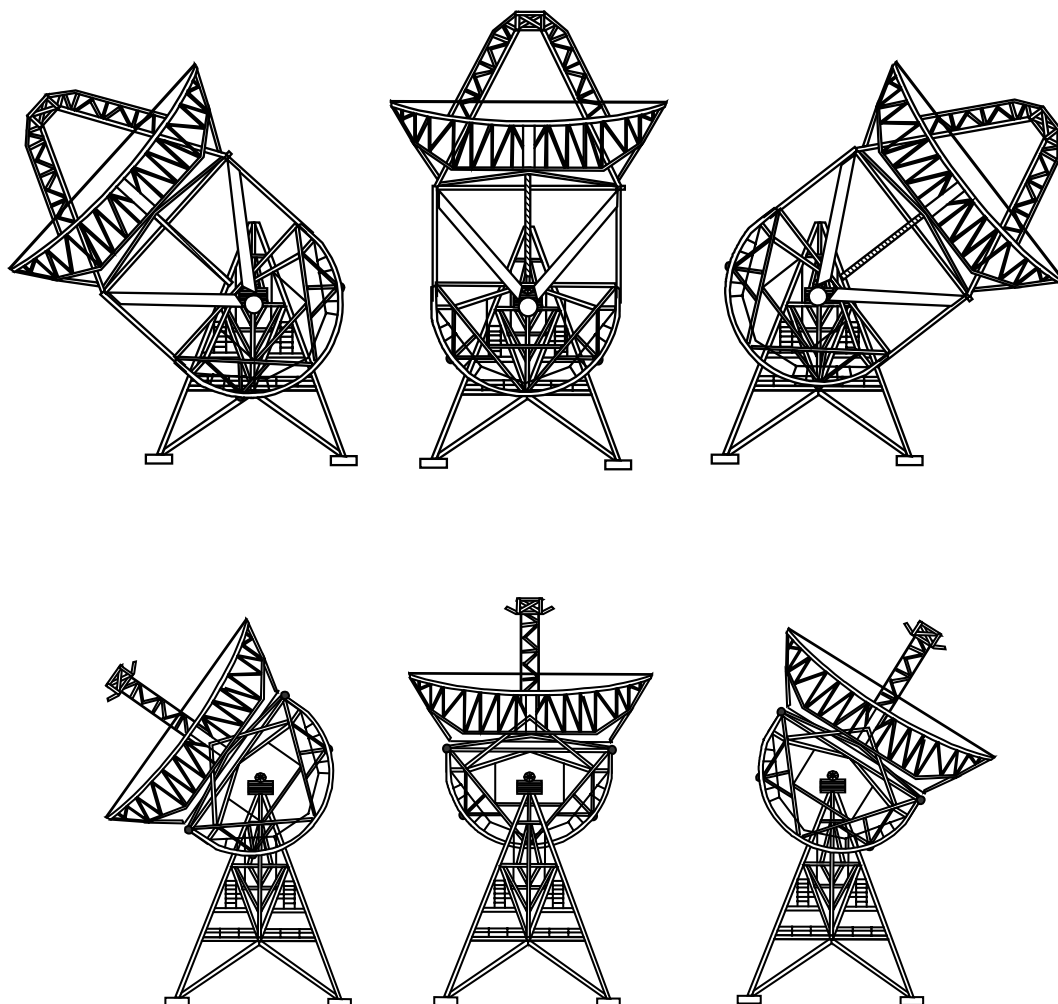


Figure 1. An X/Y antenna design. Top; view along the rotation of the X (primary) axis. Bottom; view along the rotation of the Y (secondary) axis (90° to top view). Note that this antenna design is similar to the Hobart VLBI system.

used. Precise differential levelling is used for the transfer of height and the precise height of instrument determination. Observations into the antenna/telescope system are generally made from multiple instrument stand-points, but the final network design depends on system configuration. The observations made from the standpoints are also made from within highly over-determined local geodetic network.

The classical geodetic observations are reduced in a pre-processing step that includes observation reduction, formatting, application of observation corrections including theodolite error, atmospheric, prism offsets, geoid corrections. Classical least squares geodetic adjustment is undertaken using the propriety software GEOLAB 2.4d.

4 Assumptions

The Geoscience Australia indirect approach to the determination of a system IVP relies on a number of assumptions, namely; during rotational sequence target paths scribe a perfect circular arc in 3D space (that is, there is no deformation of targeted structure during rotational sequence and there is no axis wobble error); and the primary axis can be held fixed during rotational sequence of secondary axis.

5 Axis Determination

A circular arc in space can be described by seven parameters, namely three circle centre parameters, three normal parameters (i.e. a normal vector to the plane of the circle) and a radius parameter, see Fig. 2. Initially individual circle arcs are determined from each target observed during the rotational sequence. The axes are computed using in-house developed least squares analysis software that inputs the coordinate values and variance-covariance matrix from the classical geodetic adjustment. The estimation of 3D circle parameters is undertaken constraining circle parameters where appropriate i.e. a target observed from two difference standpoints should define two circles with equal radius parameters and two targets observed on an identical axis should define two circles with equal normal parameters, see Fig 3. Residual analysis and outlier detection is also performed at this stage on the computed in-plane and out-of-plane residuals, see Fig. 4.

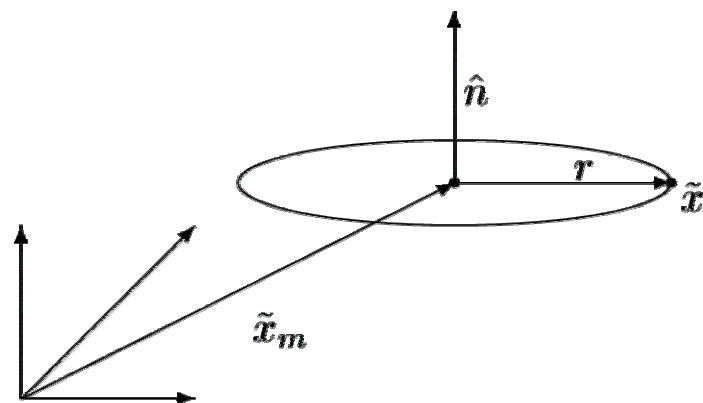


Figure 2: The seven parameters of a circle in 3-dimensional space.

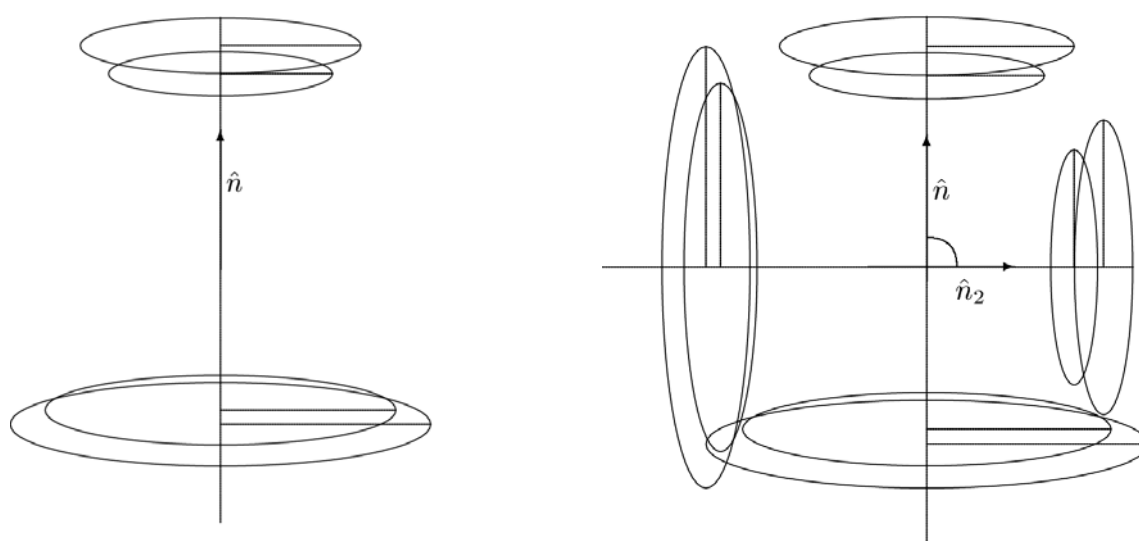


Figure 3. Inter-circle parameter relationships. Left; multiple target arcs share common normal vector parameters. Right; identical targets observed from different standpoints share common radius parameter estimates.

6 IVP determination

The determination of the IVP can then follow using the axis parameter and their associated variance-covariance matrix computed previously. In the case of intersecting systems (i.e. where the primary and secondary axes intersect), such as the Yarragadee SLR, the IVP can be computed using least square estimate of intersection point of the axes. Of course the assumption of precise intersection should first be tested both experimentally and from engineering data (if available).

In the case of non-intersecting systems, such as the Hobart VLBI, the IVP can be determined by the least squares estimate of the common perpendicular of the axes. The IVP is defined as the intersection of the primary axis and the common perpendicular between the primary and secondary axes, see Fig. 5.

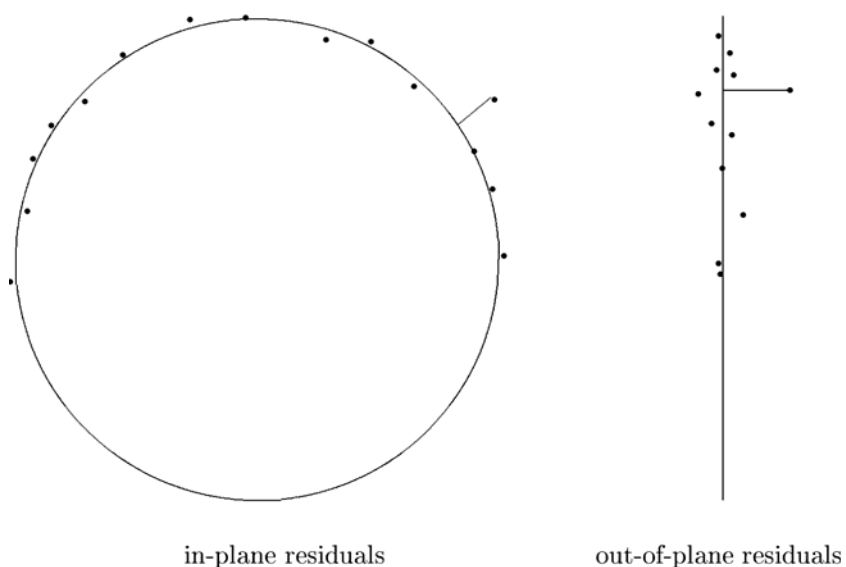


Figure 4: Circle fitting residuals.

The determined coordinates of the IVP and all stations important for co-location and their associated variance-covariance information is then ex-

tracted from the analysis software and input into the GEOLAB geodetic adjustment software. The geodetic adjustment output is then translated directly into SINEX format output.

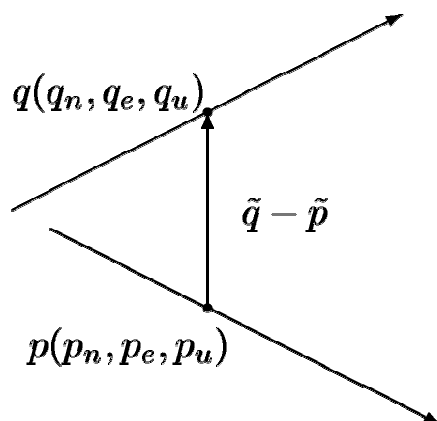


Figure 5: The common perpendicular of secondary axis (top) and primary axis (bottom) gives the IVP at the intersection with the primary axis. Point P gives the adopted definition of the IVP.

7 Australian Precision Survey Results

The number of target pointings onto the observatory structure made during the rotational sequences for each survey is summarised in Table 1. In general the systems are rotated to maximise the arc length of the target trajectory in 10° increments, although in many cases physical obstruction and rotational freedom limit the number of observations.

Table 1: Number of target pointings onto system structure.

Observatory (date)	Target-shots
Mount Stromlo (1999)	373
Mount Stromlo (2001)	224
Yaragadee (1998)	285
Yaragadee (2001)	243
Tidbinbilla DSS45 - 34m (1995)	101
Hobart - 26m (1995)	91
Hobart - 26m (2002)	298

In Table 2 the Root Mean Square (RMS) of the in-plane and out-of-plane residuals to the primary axis determination of each of the Australian observatory surveys are given. The larger RMS values of the out-of-plane residuals at Tidbinbilla and Hobart are thought at this time to result from the use of retro-reflective tape targets and as of yet un-modelled structural deformation of the antenna systems. Table 3 shows the in-plane and out-of-plane residuals of the secondary axis determination of each of the Australian observatory surveys.

Table 2: Root Mean Square (RMS) of in-plane and out-of-plane observation residuals to primary axis.

Observatory (date)	System Type	RMS in-plane residual (mm)	RMS out-of-plane residual (mm)
Mount Stromlo (1999)	AZ/EL	1.1 (AZ)	0.7 (AZ)
Mount Stromlo (2001)	AZ/EL	0.5 (AZ)	0.7 (AZ)
Yarragadee (1998)	AZ/EL	0.6 (AZ)	0.4 (AZ)
Yarragadee (2001)	AZ/EL	0.5 (AZ)	0.4 (AZ)
Tidbinbilla (1995)	AZ/EL	0.8 (AZ)	8.9 (AZ)
Hobart (1995)	X/Y	0.2 (X)	4.0 (X)
Hobart (2002)	X/Y	0.3 (X)	7.9 (X)

Table 3: Root Mean Square (RMS) of in-plane and out-of-plane observation residuals to secondary axis.

Observatory (date)	System Type	RMS in-plane residual (mm)	RMS out-of-plane residual (mm)
Mount Stromlo (1999)	AZ/EL	1.1 (AZ)	0.7 (AZ)
Mount Stromlo (2001)	AZ/EL	0.5 (AZ)	0.7 (AZ)
Yarragadee (1998)	AZ/EL	0.6 (AZ)	0.4 (AZ)
Yarragadee (2001)	AZ/EL	0.5 (AZ)	0.4 (AZ)
Tidbinbilla (1995)	AZ/EL	0.8 (AZ)	8.9 (AZ)
Hobart (1995)	X/Y	0.2 (X)	4.0 (X)
Hobart (2002)	X/Y	0.3 (X)	7.9 (X)

In Table 4 the RMS of the distance of the estimated IVP to each of the estimated axes are given. A large IVP to axis distance is indicative of the non-intersection of the axes. The estimated offset between the primary and secondary axes are also given, at Hobart an offset of 8.193 metres exists.

Table 4: Per target RMS distance of IVP to axis.

Observatory (date)	System Type	RMS IVP to axis distance (mm)	Primary axis to Secondary axis distance (mm)
Mount Stromlo (1999)	AZ/EL	3.6	1.9
Mount Stromlo (2001)	AZ/EL	1.6	0.8
Yarragadee (1998)	AZ/EL	0.6	0.3
Yarragadee (2001)	AZ/EL	1.2	0.4
Tidbinbilla (1995)	AZ/EL	7.0	7.6
Hobart (1995)	X/Y	-	8193.2
Hobart (2002)	X/Y	-	8193.0

As an additional quality check of the estimation process the Root Mean Square (RMS) minimum distance between each of the estimated axes can be computed and reviewed, see Table 5.

Survey to survey repeatability can also be reviewed as a check on the computation process. From Table 6 it can be seen that terrestrial tie repeatability is at the 1mm level. The exception to this is Yarragadee, which is thought to be indicative of the non-stability of the Yarragadee survey network. This has

been confirmed through precise levelling between all station marks at the Yaragadee observatory.

Table 5: Per target RMS distance of axis to axis distance (East, North, Up).

Observatory (date)	North RMS IVP to axis (mm)	East RMS IVP to axis (mm)	Up RMS IVP to axis (mm)
Mount Stromlo (1999)	0.1	0.3	2.1
Mount Stromlo (2001)	0.9	1.0	0.9
Yaragadee (1998)	0.4	0.3	0.4
Yaragadee (2001)	0.4	0.2	0.9
Tidbinbilla (1995)	2.3	4.1	0.9
Hobart (1995)	0.7	1.6	0.8
Hobart (2002)	0.4	1.6	0.4

Table 6: Survey to survey repeatability. Direct vector comparison from the observatory primary reference mark to the system IVP. An additional direct vector comparison between the Yaragadee GPS and SLR is also given.

Observatory	IVP	East IVP to reference mark (mm)	North IVP to reference mark (mm)	Up IVP to reference mark (mm)
Mt Stromlo (1999-2001)	SLR	-0.3	-0.4	0.4
Yarragadee (1998-2001) (from IGS GPS YAR1)	SLR	0.0 (-0.8)	1.9 (1.5)	-1.3 (-4.2)
Hobart (1995- 2002)	VLBI	-1.2	-0.3	-0.4

8 Final Remarks

To date terrestrial tie survey precision at each of the Australian geodetic observatories is approximately one millimetre (in the local frame). The further error due to the alignment to the International Terrestrial Reference Frame is more difficult to quantify but is assumed to be of the level of three millimetres but is heavily dependent on the quality/correctness of the associated GPS analysis used for alignment to the global frame.

Survey results indicate to date that the use of retro-reflective tape produces unsatisfactory results at the precision demands of this application and therefore there use in the future is to be avoided. The impact of differential refraction is yet to be fully quantified and may be significant particularly on VLBI surveys where survey observations are generally made from ground level up over several tens of metres onto the VLBI antenna structure. Structural deformation of the VLBI structure has not yet been incorporated in to the IVP determination process and remains a challenge for future survey analysis.

Acknowledgments. Alex Woods is thanked for the preparation of Figure 1.

References

Altamimi-Z.; Sillard-P.; Boucher-C., ITRF2000: A new release of the International Terrestrial Reference Frame for earth science applications. J. Geophysical Research, 107, ETG 2-1 to ETG 2-19, 2002.

The Australian Survey Report Format

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1 Introduction

In Australia precision geodetic site surveys are routinely carried out, by Geoscience Australia, at all of the significant co-located geodetic observatories to determine accurate terrestrial connections between each observing system. Sites surveyed to date include Yaragadee, Mount Stromlo, Orroral, Hobart and Tidbinbilla. At Geoscience Australia site survey reports are created and are available from the Internet. In this paper the format and content of these reports is briefly outlined.

2 Australian site survey reports

In general the Geoscience Australia site survey (local tie survey) report includes the following information:

- Background to the survey
 - When was the survey conducted i.e. survey dates
 - What was the purpose of survey i.e. routine resurvey, instrumental change, etc.
- Observations
 - Technical equipment list
 - Observation types
 - Target type eg. precise prisms, tape reflector, etc.
- Survey reductions
 - Observation corrections
 - Atmosphere model and corrections
 - Prism offsets corrections
 - Geoid corrections
 - Global Positioning System (GPS) processing summary
- Equipment calibrations
 - EDM calibrations
 - Offsets for prisms and tape
- Mark descriptions. The mark descriptions have a detail level such that any ambiguity is removed, for example
 - *AU053 (YARR)*: Domes 50107M006. The intersection of the top of the stainless steel plate with the vertical axis of a 5/8" Whitworth threaded stainless steel spigot. This pillar plate is set at ground level and is embedded in concrete to a depth of 400mm. The GPS – Glonass antenna currently occupies this monument.
 - *DON95*: Domes 50107M001, CDP 7090. Punch mark in a circular brass plaque 0.080m in diameter set in concrete. The plaque is inscribed "Australian Survey Office Survey Mark" and is stamped

DON 95. This is the primary reference point for the Moblas 5 SLR system.

- Survey network diagram; will include all reference/survey marks and inter-mark observations
- Results (see Fig. 1); final results will include
 - Final coordinates and their precision
 - Geodetic, cartesian
 - Orthometric heights in a local height datum
 - Three-dimensional line error ellipses between the fundamental marks the other significant monuments
 - site-specific information, such as the range to calibration targets from the IVP
 - Inter-survey comparisons
 - SINEX format results
 - Final conclusions

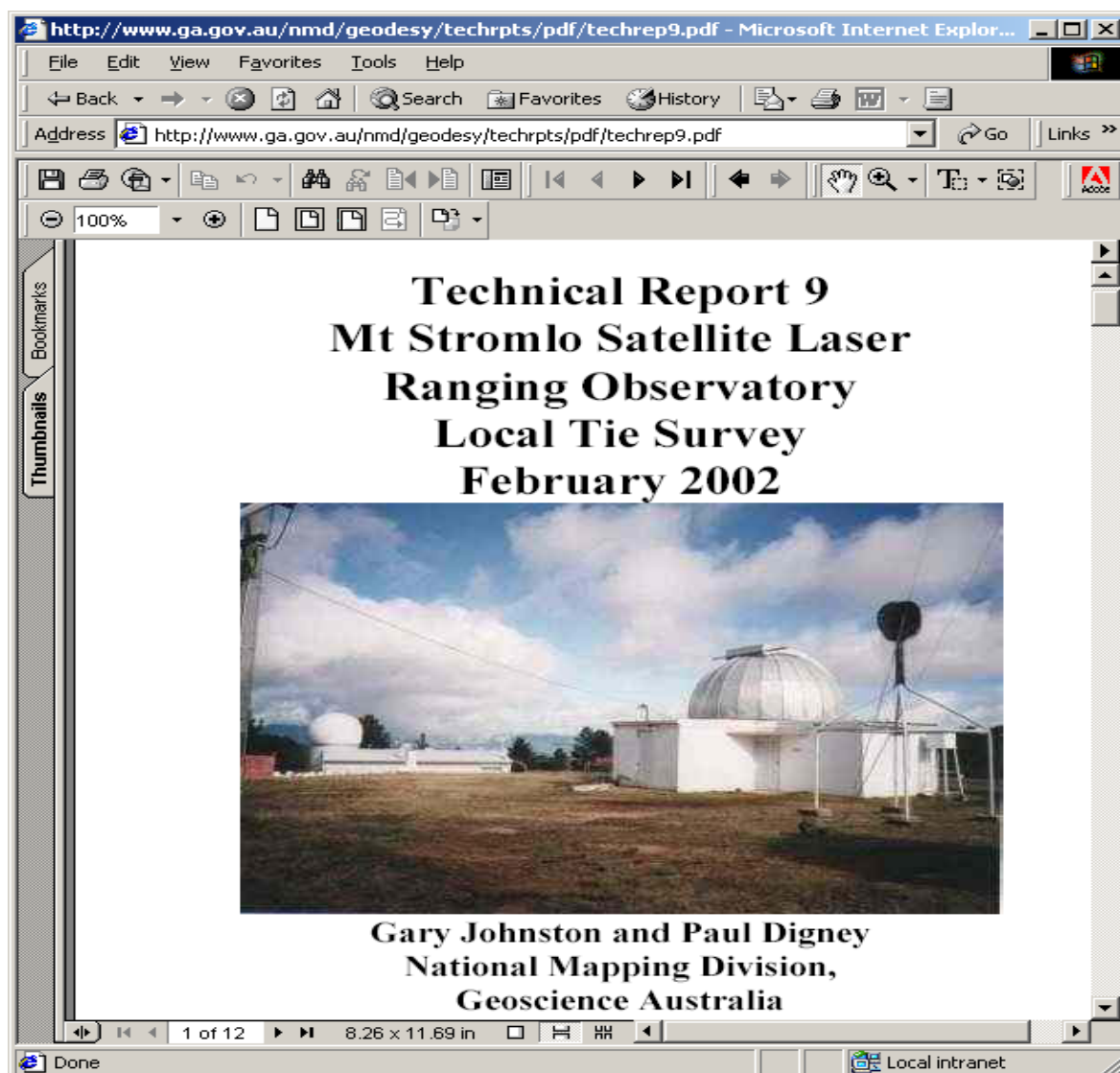


Figure 1. Title page from the 2002 Mount Stromlo local tie survey.

3 Survey database

To ensure the long term archiving and storage of the survey results all report information is stored in the National Geodetic DataBase (NGDB), which is a Windows™ relational database of geodetic positions and associated information. All survey are stored with the following information:

- Earth-centred Cartesian coordinates
- Latitude, Longitude & ellipsoidal height automatically computed
- Reference frame & epoch
- Referenced to source of positions (SINEX file)
- Exact mark descriptions
- Images & diagrams

The NGDB allows the automatic generation of technical reports that are fully user definable. Survey marks at each observatory are linked to facilitate easy report extraction.

4 Report distribution

All Geoscience Australia survey reports are deposited on the Geoscience Australia web site located at <www.ga.gov.au>. SINEX format results files are deposited on the Geoscience Australia ftp server¹.

¹ [ftp.ga.gov.au/sgac/sinex/ties](ftp://ftp.ga.gov.au/sgac/sinex/ties)

Layout of Local Tie Report

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with contributions of participants of the IERS Workshop on site co-location

Preamble

The following layout is meant as a report template for colleagues who have carried out local surveys for the purpose of local tie determinations but could also be used for other purposes like stability measurements. It has been thoroughly discussed by all attendees of the IERS Workshop on site co-location at Matera on October 23–24, 2003.

Colleagues writing reports should fill out the sections and subsections as they apply to their work and mark others as not applicable (n/a). Following this template should also prompt considerations which may otherwise be left out accidentally.

A Site Survey Document is currently being written and discussed which explains site survey procedures in more details. The report template should be understood in close connection with this Site Survey Document. Following this template ensures that interested parties have easy access to all the necessary details and to the intermediate and final results of surveys. All survey reports will be made available on an IERS Web page.

Report on Local Survey at [name of station] (year)

1 Site description

[site name, site number, domes number, general description, name and institution carrying out the survey, date of survey, maps in various scales]

2 Instrumentation

2.1 Tachymeters, EDM, Theodolites

2.1.1 Description

[automatic height index, precision stated by manufacturer ...]

2.1.2 Calibrations

[frequency, additive constants, with reflector, with reflecting tape ...]

2.1.3 Auxiliary Equipment

[barometer, thermometer ...]

2.2 GPS units

2.2.1 Receivers

2.2.2 Antennas

2.2.3 Analysis software, mode of operation

2.3 Levelling

- 2.3.1 Levelling instrument (incl. precision)
- 2.3.2 Levelling rods
- 2.3.3 Checks carried out before measurements
[additive corrections for EDM, calibration of levelling rods ...]

2.4 Tripods

2.5 Forced centering devices

2.6 Targets, reflectors

2.7 Additional instrumentation [optical plumbing instruments ...]

3 Measurement setup

3.1 Ground network

- 3.1.1 Listing
[matrix with old names, new names, monumentation, measurements carried out on individual points ...]
- 3.1.2 Map of network

3.2 Representation of reference points [e.g. model of indirect representation]

- 3.2.1 VLBI
- 3.2.2 SLR
- 3.2.3 GPS
- 3.2.4 DORIS

4 Observations

4.1 Conventional survey [distances, directions, heights of instruments and reflectors ...]

4.2 Levelling [loops, gravimetry ...]

4.3 GPS [including length(s) of GPS session(s) ...]

4.4 General comments

5 Data analysis and results [including intermediate results ...]

5.1 Terrestrial survey

- 5.1.1 Analysis software
- 5.1.2 Topocentric coordinates and covariances
- 5.1.3 Correlation matrix
- 5.1.4 Reference temperature of radio telescope
[for thermal expansion]

5.2 GPS

- 5.2.1 Analysis software
- 5.2.2 Results
[geocentric coordinates and covariances]

5.3 Additional parameters

[e.g. axis offsets]

5.4 Transformations

[UTM, Gauss-Krueger, topocentric into geocentric ...]

5.5 Description of SINEX generation**5.6 Discussion of results**

[Quality, residuals ...]

5.7 Comparison with previous surveys**6 Planning aspects**

[Network configuration, personnel, duration, weather ...]

7 References**7.1 Name of person responsible for observations**

[incl. contact information]

7.2 Name of person responsible for analysis

[incl. contact information]

7.3. Location of observation data and results archive

[incl. contact information]

Recommendations

Focused on the respective content of the session several blocs of recommendations have been discussed. There are some overlappings between the session oriented recommendations but for completeness the recommendations are published as presented.

Session 1: “Co-location sites in ITRF”

Recommendations prepared by Zuheir Altamimi with contributions of Angelyn Moore, Axel Nothnagel, Van Husson and Hervé Fagard

Some important recommendations related to local surveys and co-location sites were already addressed during the IERS Workshop in Munich 2002 (Altamimi et al, 2002). These recommendations are reproduced, emphasized and augmented below.

Recommendation 1:

In order to improve co-location sites distribution and observing networks:

- International effort is needed to improve VLBI-SLR co-locations by installing new SLR systems (e.g. SLR2000) at all VLBI sites. These are very critical for the long term TRF scale maintenance.
- IVS is urged to schedule repeated Global-TRF observing sessions;
- IDS is asked to consider installing DORIS beacons at all SLR and VLBI sites, starting with sites collocated with GPS in order to augment the number/distribution of the 4-technique “primary” sites.

Recommendation 2:

The Working Group on Local Ties is asked to organize repeated (yearly !) local surveys in the all available co-location sites. Per-site local tie components (at the survey epoch) and their time variations should be provided in SINEX format with full variance-covariance matrix. The priority list of sites (re-)surveys should be organized as follows:

- start with sites where local ties are missing and critically dubious, e.g. Shanghai
- after Earthquakes, e.g. Arequipa, Fairbanks
- Sites for which full SINEX files are not available, so that ultimately all co-location sites should have local ties expressed in SINEX format.

Recommendation 3:

The IERS Directing Board is asked to consider establishing Associated Analysis Centres for Local Ties survey and analysis, analogous to the existing Analysis Centres of space geodesy techniques.

Recommendation 4:

For the long term maintenance of co-location sites and thus the ITRF global stability, the urgent action is to envisage new design of ITRF Core Co-location Sites (ICCS), the indispensable “ITRF Pillars”, with global coverage, stable and solid monumentation, regularly/repeatedly surveyed and geophysically monitored.

Session 3: “Analysis and SINEX”

Recommendations prepared by Pierguido Sarti and Detlef Angerman with contribution of John Dawson and Patrick Sillard

The following recommendations are issues of the future IERS working group on Survey.

Recommendation 1:

A clear definition of RPs be developed by the analysis communities for each technique.

Recommendation 2:

In every cases a geodetic marker is materialized and an accurate eccentricity is re-estimated every time the local tie survey is performed.

Recommendation 3:

The Space geodetic analysis and local tie community develop new local tie products for use in analysis (e.g.: skew angle, tilt angle, wobble, structural deformations...).

Recommendation 4:

Standardized campaign procedures for homogeneous and accurate results should be adopted.

Recommendation 5:

A priori simulation of terrestrial observations should be undertaken so as to asses the impact of the survey design.

Recommendation 6:

The direct, hybrid and indirect approaches to RP determination must be compared.

Recommendation 7:

Different indirect methodologies and software must be evaluated.

Recommendation 8:

A pilot project should be set up: ad hoc survey at a representative co-location site.

Recommendation 9:

Standards on raw terrestrial data archiving and sharing must be developed.

Recommendation 10:

Agreement on type and number of stations to be included in SINEX.

Recommendation 11:

Agreement on reference frame in which local ties are expressed in SINEX and how they are mapped.

Recommendation 12:

Agreement on the generation of SINEX files (e.g.: which blocks are mandatory and which constraints are applied).

Session 5 “Workshop summary”

Recommendations prepared by Markus Rothacher, IERS Analysis Coordinator

Recommendation 1:

All local ties between co-located instruments should be determined with an accuracy of 1mm or better in the ITRF (global, cartesian) and the full variance / covariance information should be made available in SINEX format.

Recommendation 2:

Local survey measurements should have the same importance as and should be treated like any of the space geodetic techniques

Recommendation 3:

A database should be established at the IERS CB for all information in connection with site co-location (list of co-location sites, local ties in SINEX, co-location instruments, site maps and pictures, survey reports, survey status, site events and history, ...)

Recommendation 4:

Site coordinates (VLBI, GPS, SLR, DORIS) should be better tied to the ground. The local tie information should therefore be of such a quality that they can be assumed true (enforced) for the combination.

Recommendation 5:

A priority list of sites to be surveyed has to be agreed upon and a list of institutions willing to participate in survey activities (survey instruments and personnel) should be maintained

Recommendation 6:

A list of local survey analysis programs in use should be collected with the characteristics of the individual software packages

Recommendation 7:

Two different solutions (SINEX ?) should be generated, one in a local reference frame (no degradation by orientation information) and one w.r.t to the ITRF.

Recommendation 8:

All GPS sites close to other techniques should be part of the IGS routine processing.

Recommendation 9:

Standards have to be defined on how local survey results are saved in SINEX files (mandatory blocks, format modifications, constraints, NEQ and/or VAR/COVAR ...)

Annex 1 Programme of the Workshop

THURSDAY - OCTOBER 23:

08:45 - 09:00 Welcome and Introduction
(G. Bianco, and B. Richter or M. Rothacher)

09:00 - 10:30 Session 1: *Co-location sites in ITRF*
chair: Z. Altamimi, with contribution from the IERS Technique Centers
- A. Moore: IGS
- A. Nothnagel: IVS
- V. Husson: ILRS
- H. Fagard: IDS

The session will address the following subjects:

- Use and importance of co-location site survey in the ITRF
- Definition of a co-location site in terms of accuracy and distance between co-located stations
- Requirements of the IERS combination centers concerning local ties: SINEX files, accuracy
- Current status of local ties in co-location sites:
 - distribution of currently operating stations of the 4 techniques
 - quality of the currently available local ties
 - list of missing local ties
 - priority list of problematic sites
 - local tie information available at Techniques Centers (provided by a representative from each Service)

Presentations:

C. Boucher: Overview of ITRF combination and co-locations
Z. Altamimi: Position paper
A. Moore: IGS
V. Husson: ILRS (not presented)
A. Nothnagel: IVS
H. Fagard: IDS
M. Rothacher: Assessment of local ties and systematic biases between techniques from the CONT'02 Campaign processing
M. Krügel, Analysis of local ties from multi-years solutions of different techniques
D. Angermann:

Discussion

10:30 - 11:00 Morning break

11:00 - 12:30 Session 2: *Site Surveys*
chair: C. Steinforth
co-chairs: H. Fagard

Presentations:

- A. Nothnagel: Introduction to Site Surveys for co-location
- planning and strategies
 - site monumentation and local control networks
 - monitoring local site stability and footprint network
 - reference point on space geodesy instruments
 - methods and equipment
 - preliminary computations

Presentations of Examples for Completed Site Surveys:

- L. Vittuari: Station Medicina
J. Dawson: Examples from Australia

12:30 - 13:30 Lunch

13:30 - 15:00 Session 2: (continued)

- R. Haas: The 2002 local tie survey at the Onsala Space Observatory
W. Schlüter/Lechner: Station Wettzell (site survey, footprint measurements and antenna monitoring)
C. Steinforth: Station Ny-Alesund
V. Michel: Station Hartebeesthoek

Discussion

15:00 - 15:30 Afternoon break

15:30 - 17:30 Session 2: (continued)

- A. Nothnagel: Some do's and don't's in terrestrial surveying of site excentricities
J. Long: Present Draft Site Survey Standards Document
 - Review, Discussions and Recommendations
 (Comments and detailed discussion on site survey presentations)
 Goal of this session is to reach agreement on Site Survey Standards
 (presented by A. Nothnagel)

Contribution without presentation:

- S. Matsuzaka et al.: Co-location Surveys & Results in GSI's Space Geodetic Network

20:30 Dinner

FRIDAY - OCTOBER 24:

09:00 - 11:00

Session 3: *Analysis and SINEX*

chair: P. Sarti

co-chair: D. Angermann

The session aims are the following:

This session will focus on the procedures used for estimating the eccentricity vectors between different co-located space geodesy techniques using terrestrial data. The problems that relate to the definition of immaterialized Reference Points using terrestrial observations will be addressed: the different softwares used for data processing along with the geometrical constraints that have been applied within the softwares will be discussed. The tight connection between the estimation model and the surveying procedure will be highlighted. The generation of SINEX files from terrestrial data will be discussed: it is the final step of an efficient and complete local survey.

Presentations:

P. Sarti,

D. Angermann: Position Paper (presentation)

- Survey analysis strategies and software
- Generation of co-location SINEX files

Examples of computation methods:

J. Dawson An approach to the determination of the precise terrestrial connections at multi-technique geodetic observatories

V. Michel: Latest results from Hartebeesthoek

P. Sillard Local tie adjustment: from principle to implementation

M. Rothacher,

W. Schlüter Steps to generate SINEX files from the Wettzell local surveys

Discussion

11:00 - 11:30

Morning break

11:30 - 12:30

Session 4: *Reporting*

chair: A. Nothnagel

co-chairs: B. Richter

The first part of Session 4 is concerned with the survey reporting document, the report content, the level of detail, the organization and the format. Alex Nothnagel, John Dawson, Michel Valerie, and Wolfgang Schlueter will present examples of survey reports already produced. A strawman report template for the standard report will be presented for discussion. In this part of Session 4, we will try to come to closure on a standardized report content and structure. If we cannot come to closure, we will identify the issues of disagreement and a path toward resolution.

Presentations of Example of survey reports

- J. Dawson: Geoscience Australia
- V. Michel: IGN

12:30 - 13:30

Lunch

- 13:30 - 15:00 Session 4: (continued)
- Survey report template and survey data reporting:
- A. Nothnagel: Report Template
- This section of the session will discuss the content, level of detail, and format of a survey report, with the goal of agreement on a standard report.
- Angelyn Moore: Proposal for site documentation
- Z. Altamimi, B. Richter: Site survey database
- In continuation of the previous discussion this part of the session will address the following subjects:
- Review of existing information available at different WEB/ftp areas related to Local Survey in co-location sites
 - IERS database concept and realization
 - proposal for an IERS Local Survey database, including survey data, reports, SINEX files and description of markers and instrument reference points in the co-location sites.
- 15:00 - 15:30 Afternoon break
- 15:30 - 17:30 Session 5: *Planning for 2004*
chair: C. Ma
co-chair: M. Rothacher
- Survey capability and availability for co-location
 - Survey planning for 2004
 - Workshop summary (all session chair, IERS CB)
 - list of agreed-upon standards, methods, formats, etc.
 - list of items needing further discussion
- M. Rothacher: Status and organization of site survey activity within IAG, IAG Commission 1 and IERS Working Groups
- planning of next meeting
 - RECOMMENDATIONS

Annex 2

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